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Firms Operating under Electricity Constraints in Developing Countries

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Many developing countries are unable to provide their industrial sectors with reliable electric power, with the result that many enterprises must contend with an insufficient and unreliable supply of electricity. Because of these constraints, enterprises often opt for self-generation of electricity even though it is widely considered a second-best solution. This paper develops a theoretical model of investment behavior in remedial infrastructure in the presence of physical constraints. It then illustrates the model's predictions using a large cross-country sample of enterprises from the World Bank Enterprise Survey database. Electricity-intensive sectors in high-outage countries are characterized by a significantly lower share of small firms. JEL codes: H54, L94, L16

And God said, 'Let there be light' and there was light, but the Electricity Board said He would have to wait until Thursday to be connected.

Spike Milligan

INTRODUCTION

Growing evidence, both micro- and macroeconomic, suggests that better electricity infrastructure significantly boosts economic growth and improves a range of development outcomes.[1] Low levels of infrastructure development and

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1. See, for example, Calderón and Servén (2003) and Calderón (2009) for cross-country estimations and Dinkelmann (2009) and Lipscomb, Mobarak, and Barham (2011) for microeconomic evidence.

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poor quality services can drive up firms' costs and bias their technological choices away from energy intensive choices, increasing the overall costs relative to competitors in other regions.[2] In developing countries, enterprises typically have difficulty connecting to the public grid[3] or, when they are connected, face frequent scheduled and unscheduled power cuts. Fluctuations in voltage and the frequency of power cuts cause material losses and adversely affect manufacturing costs and output.

To offset these negative impacts, industrial firms in developing countries often opt for self-generation of electricity, even though it is widely considered a second-best solution. Of the 25 sub-Saharan countries reviewed by Foster and Steinbucks (2009), in-house generation accounts for more than 25 percent of the installed generating capacity in three countries and for more than 10 percent in nine others. In Nigeria, where 40 percent of the electricity consumed is produced with generators, firms spend up to 20–30 percent of their initial investment enhancing the reliability of their electricity supply.[4] Moreover, in Africa, self-generated electricity is 313 percent more expensive on average than electricity from the grid. Foster and Steinbucks (2009) conclude that the main victims are likely to be the existing informal firms and the formal firms that were not created as a result of the prevailing constraints.

We use a large firm-level dataset to analyze the behavior of firms facing electricity constraints. Our objective is to understand the conditions under which they decide to invest in their own generating capacity, how this decision is affected by the abovementioned constraints, and ultimately, what this decision implies in terms of firm-size distribution. Our original contribution is, first, to document systematically the effects of electricity deficiencies on the decision to invest in mitigating technology (i.e., a generator); second, to analyze how the impact of electricity deficiencies varies across firms and sectors; and, finally, to show how these deficiencies affect the resulting patterns of industrial structure across countries and sectors. A theoretical model of firm responses to power outages allows us to derive precise predictions that are illustrated by the data. We show that electricity-related constraints have nonlinear effects that vary according to the degree of the sector's reliance on electricity. In sectors that are naturally more reliant on electricity, a large number of outages implies a skewed industrial structure with many large firms and fewer small ones.

Related contributions include Lee, Anas, and Oh (1996) and Lee and others (1996), both of which use data from Nigeria, Indonesia, and Thailand. These studies conclude that public infrastructure deficiencies have substantial private costs with the burden falling disproportionately on smaller firms. They also point out significant differences across the three countries, particularly in terms of the regulatory environment. Hallward-Driemeier and Stewart (2004) and

2. Eifert, Gelb, and Ramachandran (2008).

3. World Bank (2004); Bartelsman, Haltiwanger, and Scarpetta (2004).

4. Adenikinju (2005).

Dollar, Hallward-Driemeier, and Mengistae (2005) document patterns of access to infrastructure services by enterprises in developing countries and show that access varies by type of service and firm size, with electricity often being the largest barrier to entry and larger firms expressing more concerns than smaller firms about all services. In Bangladesh, China, Ethiopia, and Pakistan, improvements in the reliability of the power supply are found to increase total factor productivity in garment manufacturing as well as output and employment growth rates. Gulyani (1999) documents the impact of electricity hazards on an Indian car manufacturer and its upstream suppliers, which have devised an innovative generation and power-sharing system to solve their power problems. Reinikka and Svensson (2002) analyze a sample of 171 Ugandan firms, some of which responded to poor electricity supply by investing in generators, and show that this development came at the cost of reduced overall investment and less productive capital.

The paper is structured as follows. Section 2 presents the enterprise survey dataset and provides descriptive statistics on the extent of electricity deficiencies. Section 3 presents a model of investment by firms with infrastructure constraints. Section 4 presents the econometric specifications used to test the model's predictions. Section 5 presents the results, section 6 addresses some limitations of the data, and section 7 describes selected policy implications and concludes.

Data and Stylized Facts

We use data from enterprise surveys for 87 countries for which data on the number of power outages are available, covering a total of 46,606 firms over the period from 2002 to 2006.[5] For 77 countries, data on generators are available, and for 34 countries, data on the cost of electricity are available.[6]

It is important to note that these surveys are limited to formal registered firms with five or more employees, primarily in the manufacturing and services sectors. The implications for informal firms and the effect of the constraints that we discuss here on formal-informal choice are addressed in several places below.

Table 1 shows the severity of electricity hazards across regions and country income groups. Column 1 reports the percentage of firms' managers who cite electricity as a major or severe constraint on their operations and growth. This is the case for more than 26 percent of firms located in low-income countries, with the highest percentage in South Asia (43 percent of firms), followed by

5. See https://www.enterprisesurveys.org. The list of countries can be found in table S.1 in the supplemental appendix, available at http://wber.oxfordjournals.org/. Unfortunately, it is not possible to use survey data after 2006 because key questions about power were dropped from the questionnaire.

6. This yields a sample of 62 countries with data on generators and number of power outages and 32 countries with data on generators, number of power outages, and cost of electricity. The full description of the variables is in table S.2 in the supplemental appendix.

TABLE 1. Access to Electricity by Firms across Regions and Country Income Groups

Region	Percent of firms mentioning electricity as major or severe constraint	Average number of power outages	Percent of firms with more than 30 power outages	Generator ownership (percent of firms)
Europe/Central Asia	8.5%	9.72	5.7%	27.5%
Latin America	9.3%	12.44	7.7%	21.2%
East Asia and Pacific	25.1%	36,49	18.3%	28.7%
Mid. East/ North Africa	21.5%	41.32	22.1%	32.4%
Sub-Saharan Africa	16.4%	61.12	45.2%	36.6%
South Asia	43.0%	131.74	49.0%	61.7%
Country Income Level				
High	4.9%	1.32	0.2%	-
Upper-middle	8.3%	13.02	6.2%	28.0%
Lower-middle	14.3%	13.76	9.1%	24.1%
Low	26.4%	64.08	34.1%	42.4%
Average	15.6%	27.57	15.2%	31.1%

Source: Authors' analysis based on data described in the text.

East Asia and Africa. Columns 2 and 3 report the average number of power outages suffered by firms and the share of firms that suffered more than 30 outages in the year prior to the survey. The average number of cutoffs from the public electricity grid faced by firms per year is as high as 132 in South Asia and 61 in Africa. Furthermore, in these two regions, close to half of all the firms surveyed experienced more than 30 outages per year. Note that firms can report multiple outages per day and that these are counted as separate episodes.

The picture provided by these indicators is consistent across regions and income groups. Outages are a particular problem in low-income countries, with peaks of approximately 250 outages per year in Bangladesh and 180 in Lebanon and the Democratic Republic of Congo. As a result, many firms invest in a back-up power generator: 31 percent of all firms own or share a generator, with this number peaking at 62 percent and 37 percent in South Asia and Africa, respectively. Note that there is no information in the dataset on the intensive margin of generator use. Firms with installed generator capacity are typically larger, are slightly older, and report more days without power from the public grid during the survey year. Conversely, firms that do not own generators are smaller and are found mostly in environments with fewer outages. General firm-level summary statistics are available in table S.3 in the supplemental appendix, available at http://wber.oxfordjournals.org/.

Table 2 presents estimations, including firm characteristics and country fixed effects. In regressions without characteristics, the fraction of the overall variance of generator ownership explained by country fixed effects is 19 percent, while for outages variance, it varies between 12 percent (among firms with a generator) and 28 percent (for firms without a generator).

Firm size explains approximately 10 percent of the variance in generator ownership, whereas ownership and exporting status explain between 1 percent and 3 percent. In contrast, none of the variance in outages is due to these characteristics. Large firms as well as foreign-owned, exporting, and capital city-based firms report owning a generator relatively more frequently than other firms, and all coefficients are highly significant. Regarding outages, the picture is more complex. In the sample of firms that own generators, large firms appear to face more outages than smaller ones, whereas the opposite is true for firms without generators. This pattern is largely the result of selection because large firms that are more exposed to outages are also more likely to invest in self-generation, whereas small firms that would benefit from a generator may not be able to afford one. Moreover, most of these characteristics, particularly that the characteristic of a capital city location, are not significant. Together with the fact that these characteristics fail to explain a significant share of the overall variance, this leads to limited concerns about the potential endogeneity of outages, which would derive, for example, from strategic decisions by governments about how and where to allocate outages or by firms about where to locate.

The Model

We are primarily interested in the link between firms' decisions to invest in self-generation and the quality of the electricity supply (measured by the number of outages). The model develops a simple moral hazard credit framework, which shows that this link crucially depends on the firm's net worth and its dependence on a reliable electric supply. As shown formally below, when losses related to electricity deficiencies are limited, firms at all levels of assets are able to operate, and only those above a given size threshold find it profitable to invest in a generator. This threshold increases in the level of electricity efficiency. However, when such losses are high, firms that do not own a generator have very low returns and become unable to operate. Thus, the model provides predictions with respect to the structure of the industry, particularly the fact that when facing a large number of outages, sectors that are sensitive to the efficiency of the electric supply should be characterized by a lower proportion of small formal firms.

We consider a continuous moral hazard investment model, à la Holmstrom and Tirole (1997). Firms are endowed with assets A, such as cash or productive assets that they can pledge as collateral. To undertake an investment project of variable size I, firms intend to borrow an amount $I - A$.

TABLE 2. Generator Ownership and Frequency of Outages by Firm Characteristics

		Generator ownership			
		Estimated coefficients	Standard errors	Within R^2	Fraction of nonexplained variance due to country F.E.
Without Control	*N*	*43 646*			
	Constant	0.311	0.002	0.000	0.192
By firm size*	*N*	*37 623*			
	Constant	0.501	0.004	0.099	0.235
	Small	−0.368	0.006		
	Medium	−0.200	0.005		
By firm ownership	*N*	*42 742*			
	Constant	0.295	0.002	0.013	0.199
	Foreign	0.159	0.007		
By firm exporting status	*N*	*42 409*			
	Constant	0.267	0.002	0.029	0.199
	Exporter	0.184	0.005		
By firm location	*N*	*31 436*			
	Constant	0.330	0.003	0.000	0.188
	Capital City	0.017	0.007		
		Number of power outages			
Firms with generator		Estimated coefficients	Standard errors	Within R^2	Fraction of nonexplained variance due to country F.E.
Without control	*N*	*8 745*			
	Constant	68.836	1.503	0.000	0.122
By firm size*	*N*	*6570*			
	Constant	60.993	1.391	0.001	0.358
	Small	−3.240	2.781		
	Medium	1.357	2.053		
By firm ownership	*N*	*8625*			
	Constant	69.081	1.667	0.000	0.121

	Foreign	0.313	4.791		
By firm exporting status	*N*	*8485*			
	Constant	65.941	1.504	0.000	0.186
	Exporter	4.238	2.659		
By firm location	*N*	*7164*			
	Constant	78.368	2.511	0.000	0.116
	Capital City	0.080	5.225		
Firms without generator		Estimated coefficients	Standard errors	Within R^2	Fraction of nonexplained variance due to country F.E.
Without control	*N*	*16 298*			
	Constant	25.891	0.563	0.000	0.278
By firm size*	*N*	*13243*			
	Constant	20.306	0.868	0.001	0.537
	Small	0.598	1.122		
	Medium	2.265	1.037		
By firm ownership	*N*	*15721*			
	Constant	26.319	0.620	0.000	0.272
	Foreign	0.824	2.171		
By firm exporting status	*N*	*15726*			
	Constant	25.923	0.663	0.000	0.275
	Exporter	1.087	1.593		
By firm location	*N*	*13480*			
	Constant	28.501	0.852	0.000	0.278
	Capital City	−1.409	1.776		

Source: Authors' analysis based on data described in the text.

Note: The within R^2 indicates the fraction of the variance of Y explained by the relevant characteristics (size, ownership, exporting status and location).

* Small firms have strictly less than 20 employees, medium firms employ between 20 and 99 workers, and large firms have more than 100 employees.

The net return on an investment project depends on a complementary input (in this case, electricity from the grid), the provision of which is of varying quality. We assume that this net return is given by δr, where r is the gross return absent any infrastructure constraints and $\delta \in [0,1]$ captures the impact of the electricity supply. In practice, the quality of the supply as measured by the number of outages interacts with the sector-level "sensitivity to electricity" to determine the actual value of δ. In particular, when operating at the technological frontier, some sectors are naturally more reliant on electricity than others are. For sectors with a higher sensitivity to electricity, a given number of outages has a stronger negative impact on the project return.[7] Formally, we consider a simple version of this differential sensitivity corresponding to our empirical application below, in which there are two types of sectors with either high (indexed by H) or low (L) sensitivity, with $\delta_H(0) = \delta_L(0) = 1$ and $0 < \delta_H(N) < \delta_L(N) < 1$ for all $N > 0$.

The project yields δrI in case of success and 0 in case of failure, an outcome that is fully verifiable. However, the probability of success depends on the effort exerted by entrepreneurs, which is not observable by the lender. If the entrepreneur works, the probability of success is p_H, whereas if the entrepreneur shirks, the probability of success is only $p_L < p_H$. However, in shirking, he enjoys a private benefit BI or, equivalently, saves on the cost of effort.

The project is viable only if the project's net present value per unit of investment is positive. We assume that it is always negative if effort is not exerted ($p_L\delta r + B < 1$ for all $\delta \in [0, 1]$), but it may be positive if effort is exerted. In other words, there is a threshold $\delta_0 \equiv 1/p_H r$, such that $p_H\delta r > 1$ for all $\delta > \delta_0$. In contrast, if $\delta < \delta_0$, the unit net present value is too low, and the project is not worth undertaking. It follows from the model's assumption above that in sectors with a high sensitivity to electricity, the number of power outages N such that $\delta < \delta_0$ is lower.

The credit contract consists of an amount I and shares corresponding to the borrower (R_b) and the lender (R_l), such that $\delta rI = R_b + R_l$. The incentive constraint of the borrower is given by

$$p_H R_b \geq p_L R_b + BI \Leftrightarrow R_b \geq BI/\Delta p, \qquad (1)$$

which defines the maximum income pledgeable to the lender $R_l = \delta rI - BI/\Delta p$. Moreover, the lender must at least break even, which implies that

$$p_H R_l \geq I - A. \qquad (2)$$

7. This stronger negative impact results because the production process relies on electricity and is therefore more affected by outages or because deficiencies push firms to adopt technologies that are farther away from the frontier.

The problem is solved by assuming that the credit market is competitive such that profits are null and (2) is binding. After straightforward computations, we can characterize the level of investment as

$$I \leq k^{\delta} A, \tag{3}$$

where $k^{\delta} = 1/[1 + (p_H B/\Delta p) - p_H \delta r]$. In a competitive credit market, borrowers receive all of the surplus, which can be written as $U_b^{\delta}(A) = (p_H \delta r - 1)I = (p_H \delta r - 1)\, k^{\delta} A$, and they invest the maximum possible amount ($I = k^{\delta} A$).[8]

Alternatively, the firm can invest in a private substitute to ensure reliable electricity input (i.e., an electric generator). This investment has a cost κ, leaving the firm with an initial capital $A - \kappa$. However, the firm ensures a return R^G, such that $R^G < r$.[9] In that case, the firm proceeds to invest $I^G = k^G(A - \kappa)$, where

$$k^G = 1/[1 + p_H B/\Delta p - p_H R^G]. \tag{4}$$

The firm receives utility

$$U_b^G(A) = (p_H R^G - 1) k^G (A - \kappa). \tag{5}$$

Optimal Firm Decision

Let us now compare the benefits of investing or not investing in a generator at different levels of wealth A. From the expressions of $U_b^{\delta}(A)$ and $U_b^G(A)$, we can draw figure 1.

Figure 1.A represents the case in which $\delta > \delta_0$, that is, the impact of electricity deficiencies is not overly severe. In this case, two types of investment behavior coexist. Below the cutoff level A^*, firms do not invest in generators but are able to obtain credit and enter production, whereas above the threshold, large firms invest in generators and obtain greater leverage in the credit market.[10] When power from the grid is reasonably reliable, entry into the productive sector is profitable across the range of potential entrepreneurs and sectors. A duality exists in terms of access to remedial investments and productivity, and A^* is increasing in δ, meaning that as long as $\delta > \delta_0$, an increase in power cuts will trigger additional investments in generators.

8. The assumptions on the net present value imply that $k^{\delta} > 1$. We also need to assume that $p_H \delta r < 1 + p_H B/\Delta p$ to ensure that the optimal size of the firm is not infinite.

9. The assumption $R^G < r$ captures the fact that the unit electricity cost from a generator is higher than that from the grid (see Foster and Steinbuks, 2009). It is a shortcut for a characterization with both a fixed and a variable cost of operating the generator, which would yield similar qualitative results.

10. Note that we represent the case $k^G > k^{\delta}$. If k^{δ} exceeds k^G, which is likely if the electric supply is completely flawless, firms borrow and produce at any level of wealth without the need to invest in a generator. Our data support the idea that this case is not relevant in our sample.

FIGURE 1. Investing in a Generator at Different Levels of Wealth

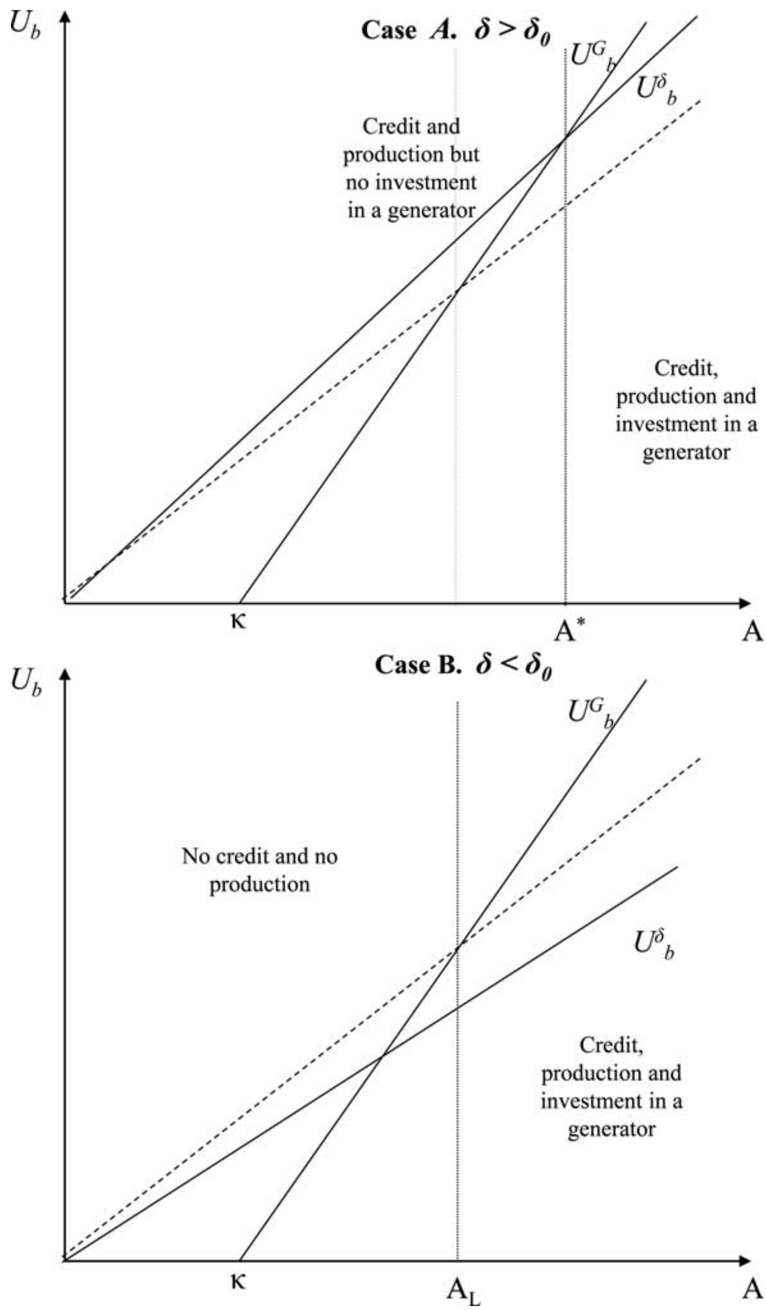


Figure 1.B represents the case in which $\delta < \delta_0$, that is, when the impact of outages is severe. The outcome is stark: firms above a cutoff level A_L invest in complementary capital, take credit, and enter production, whereas firms below

the cutoff are credit constrained because infrastructure deficiencies are so stringent that the return from production is too low to access the credit market, and these firms lack the capacity to invest in a generator. Notably, in contrast to the previous case, A_L does not depend on δ as long as $\delta < \delta_0$. Although this situation is not explicitly modeled here, one can imagine that these potential entrepreneurs remain in the informal sector.

The cases in figure 1 can be understood as capturing two types of variation in the environment. First, they may reflect the difference between countries with reliable electric services and those with a relatively higher prevalence of outages. Second, they may relate to the sector-level fundamental characteristics discussed above, the sensitivity to electricity.

Proposition 1 summarizes the insights from figure 1 and states that the probability that a firm owns a generator increases with the number of outages N as long as the impact of electricity deficiencies is small ($\delta > \delta_0$), whereas this probability does not depend on N when this impact is strong ($\delta < \delta_0$) because investment is discouraged altogether. [11]

Proposition 1 *There is a threshold* δ_0 *such that* $\partial A^*/\partial\delta > 0$ *if and only if* $\delta > \delta_0$, *whereas for* $\delta < \delta_0$, $\partial A^*/\partial\delta = 0$.

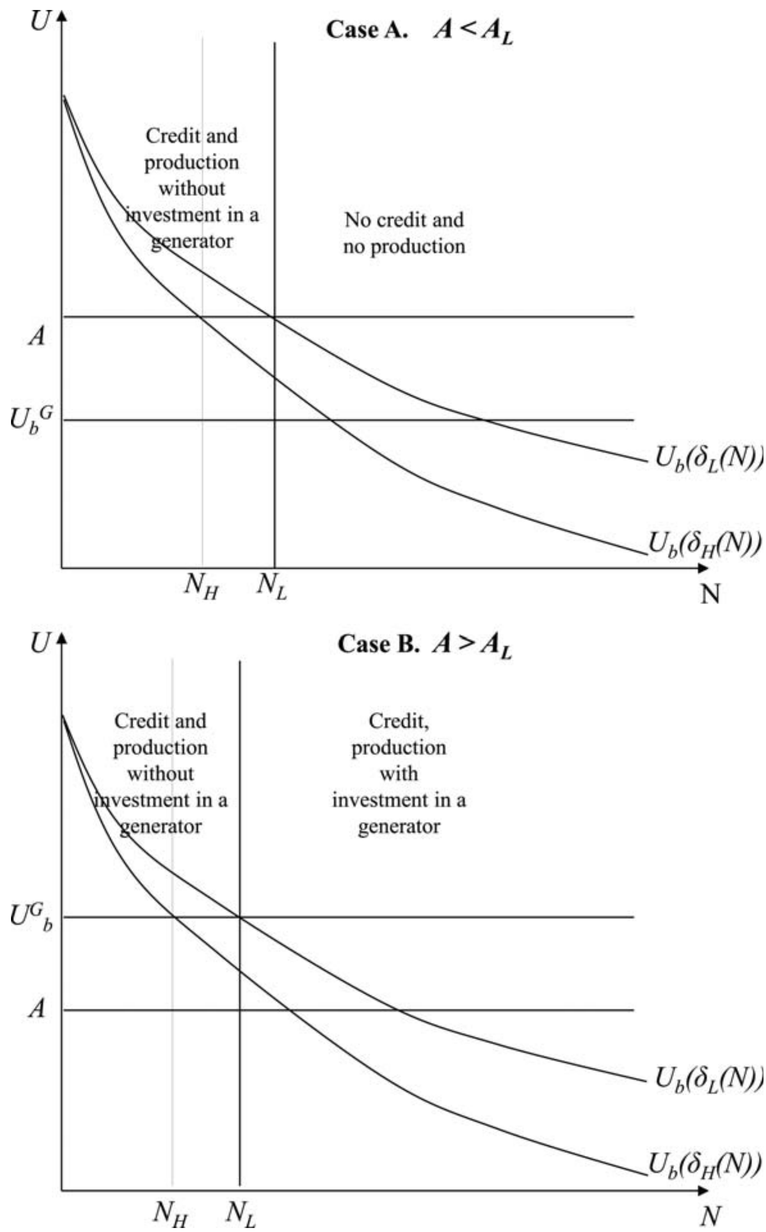
The model has implications for firm size distribution, as illustrated in figure 2. In sectors that are very sensitive to electricity, there will be fewer small firms, and among existing (medium and large) firms, a larger proportion of firms will own a generator.

Figure 2, which represents the profit of a firm of fixed size $A < A_L$ (i.e., a relatively small firm) as the number of power outages N varies, illustrates the first part of this prediction. The downward sloping curves denoted $U_b(\delta_L(N))$ and $U_b(\delta_H(N))$ represent how the firm's utility evolves with the number of outages in low-sensitivity and high-sensitivity cases, respectively. The cutoffs N_H and N_L on the horizontal axis show the number of power outages above which small firms are pushed to exit the market. These cutoffs correspond to the limit case for $A < A_L$ in figure 1 between cases A and B, when the increase in outages drives down the slope of U_b^δ to that of the dashed line ($A = U_b^\delta$). For small firms, crossing this threshold means going from a situation in which they can operate despite not owning a generator to one in which they experience losses and stop operating. Figure 2.A thus shows that in the presence of electricity deficiencies, there is a smaller proportion of small firms.

Figure 2.B illustrates the second part of the prediction. This figure represents the profit of a firm of fixed size $A > A_L$ (i.e., a medium or large firm) as the number of power outages N varies. The cutoffs N_H and N_L are defined as before and now show the number of power outages above which the firm finds it profitable to invest in a generator, corresponding to the limit case between cases A and B in figure 1. Here, the proportion of firms that do not own a generator is smaller in sectors that are more sensitive to electricity.

11. Proofs are straightforward and are therefore omitted.

FIGURE 2. Firm Profits and Power Outages



We summarize these insights in proposition 2.

Proposition 2 *Deficiencies in the electricity supply have different impacts on the distribution of firms' size depending on sector characteristics. In sectors that are comparatively more sensitive to the efficiency of the electric supply, a* *large number of outages results in small formal firms being relatively less abundant.*

Note that this simple model is necessarily silent on some additional issues, such as the fact that firms' exposures to outages may be endogenously determined and that credit constraints and exposure to outages may be correlated to other unobserved attributes of firms, such as their political or business connections. More generally, these aspects form part of the identification issues that arise from the data, which we discuss in sections 5 and 6 below. The next section presents the econometric specifications used to test these implications.

Econometric Specifications

The model specified above leads us to test the following empirical specifications regarding the decision to invest in an electric generator, which we can write as a binary decision problem:

$$Gen_{ijc} = 1[Gen^{*} = \theta_j + \theta_c + \theta\_t + \alpha log N_{ijc} + X_{ijc}\gamma + \epsilon_{ijc} > 0], \tag{6}$$

where *1[.]* is an indicator function equal to one if the statement in brackets is true; i indexes firms; *Gen* is a binary variable equal to one if the firm owns a generator and zero otherwise; the θs are sets of dummy variables for industries (j), countries (c), and years (t); N_{ijc} is a measure of the number of power outages facing the firm; and X_{ijc} is a vector of firm-level controls, including measures of possible financial constraints.[12]

The logarithmic term is meant to capture, in a very generic fashion, the nonlinear effects of power outages outlined in the model. We expect $\alpha > 0$, meaning that the probability of owning a generator will increase with the increasing prevalence of outages.

The model also implies that the coefficients should differ according to the intrinsic sensitivity of productive sectors to the quality of the electric supply. One important question is how to define this latter aspect. On the basis of the average sector-level value of electricity expenditures as a percentage of total cost, we define S_h as a dummy variable equal to one for sectors relying heavily on electricity as an input and zero otherwise.

To mitigate potential concerns linked to the fact that technology choice is, to some extent, endogenous—so that industries in environments with many outages may substitute technologies that use less electricity—we restrict ourselves to countries with relatively low electricity constraints when defining S_h.[13]

12. Note that although we include year dummies to address the fact that not all surveys are from the same year, in the few cases in which we have surveys corresponding to different years in the same country, we treat them as different independent samples.

13. This is standard practice in the empirical literature. Examples of industry-level reference values for innovation or barriers to entry can be found, for example, in Rajan and Zingales (1998) and Fisman and Sarria-Allende (2004).

The underlying logic is to have a reference value of what technological choices would look like in a distortion-free environment, akin to a sectoral technological frontier. Our assumption is that in sectors in which the first-best technology would be electricity intensive, the impact of deficiencies will be felt more strongly and will penalize firms more heavily because firms that do not own generators would either suffer critical failures and damages or would have to settle for second-best technologies; both cases imply a larger efficiency gap. We discuss the technical details of the variable construction further in the next section.

Equipped with this measure, we can add an interaction term $S_h^* N_{ijc}$ to (6), which we expect to be negative if a marginal increase in the number of outages has a lesser impact in electricity-intensive sectors (see proposition 1).[14]

The second set of predictions concerns the differential distribution of firm size across sectors. To address this, we estimate difference-in-differences across sectors (following the classification according to S_h defined above) and countries, distinguishing between countries with a high or small median (or average) number of outages. Formally, we estimate

$$Z_{jc} = \alpha + \beta S_h + \delta C_h + \gamma(S_h^* C_h) + \epsilon_{ijc}, \tag{7}$$

where Z_{jc} is an industry- or country-level measure of the relative number of small firms. On the right-hand side, the coefficient γ of the interaction term is the difference-in-differences estimator. Consistent with proposition 2, this equation captures the extent to which moving from the level of outages of the below-the-median group of country ($C_h = 0$) to the above-the-median one ($C_h = 1$) reduces the abundance of small firms by comparing the reduction in the group of electricity-intensive industries ($S_h = 1$) to that observed in non-electricity-intensive industries ($S_h = 0$).

Empirical Analysis

To estimate the specification above, we first need to construct the parameter S_h. The countries in our sample with the smallest number of power outages are Indonesia, Lithuania, Brazil, Poland, and Thailand, with a reported average of 2.66 per year across these countries. Within this subsample, we compute the average cost of electricity as a percentage of total cost by industrial sector.[15] We classify industrial sectors that are above the median (7.7 percent) as "very reliant on electricity" ($S_h = 1$) and the remainder as sectors that are not heavily reliant on electricity ($S_h = 0$). Because not all industrial sectors are represented

14. In a previous version of this paper (Alby, Dethier, and Straub, 2010), we approximated the nonlinear shape with a quadratic specification of outages instead of the logarithmic one and showed that the turning point was lower for electricity-intensive sectors.

15. See table S.4 in the supplemental appendix, available at http://wber.oxfordjournals.org/.

in our subsample of five countries with reliable electricity services, we assign a value for S_h in eight missing industrial sectors following intuitive criteria.[16]

Finally, a few sectors have a low number of valid observations. Considering their cost share of electricity in the full sample of countries leads us to consider an alternative classification, with *Other services* in the $S_h = 1$ group and *Retail and wholesale trade* in the $S_h = 0$ group. In tables 4 and 5 below, we systematically provide robustness checks using this alternative S_h classification.

Table 3 presents summary statistics on these two subsamples of firms.

The results of estimating equation (6) by maximum likelihood using a probit model are shown in table 4, with marginal effects reported. All specifications include country, industry, and year dummies, and standard errors clustered at the industry level. We first introduce the number of power outages in columns 1 to 3. Column 1 reports the results with country, industry, and year dummies only, and column 2 reports the results with firm-level controls (age of firm, location, whether it exports, whether it has foreign capital, and firm size). To the extent that more power outages are likely to lead to more generator ownership, we expect the coefficient for the number of outages to be positive, and this is indeed what we obtain. In column 2, a 10 percent increase in the number of outages adds 0.3 percent to the probability that firms own a generator. In column 2, the coefficients of the age, capital city, and, particularly, export and foreign ownership dummies (not shown to save space) are large, positive, and significant, and their inclusion actually reinforces the effects of power outages.

Column 3 introduces several measures of financial constraints: whether access to financing is a major or severe constraint, whether the cost of financing is a major or severe constraint, and whether the firm has access to an overdraft facility or line of credit.[17] These variables have the expected effect on the probability of owning a generator: more stringent constraints decrease this probability, and more important, their inclusion does not invalidate the results for outages. Of course, both firm-level controls and financial constraint proxies should be considered control variables for the sake of robustness, and their respective coefficients should not be interpreted as causal because specific endogeneity concerns arise from omitted variable bias and unobserved effects, such as entrepreneurial skills.

16. A core set of sectors is systematically included in all enterprise surveys, so the missing ones represent relatively few firms overall (see Dethier, Hirn, and Straub, 2011, for a detailed description). We consider sports goods, other manufacturing, and mining and quarrying industrial sectors that do not rely heavily on electricity (their cost share of electricity is less than 3.5 percent in the full sample of countries), and we assign these sectors, as well as accounting and finance and advertising and marketing, a value of $S_h = 0$. Symmetrically, we assign a value $S_h = 1$ for firms operating in IT services, hotels and restaurants, and telecommunications (average cost share of electricity above 8.6 percent in the full sample for the first two).

17. Descriptive statistics on these credit constraints measures are in Alby, Dethier, and Straub (2010).

TABLE 3. Describing Firms' Sub-Samples According to S_b

	S_b		
	0	1	TOTAL
Whole Sample			
Number of firms	20,064	20,651	40,715
Percentage of firms quoting electricity as a major or severe constraint	18.81%	15.88%	17.33%
Average number of power outages	22.71	23.18	22.95
Percentage of firms with a generator	28.59%	40.39%	33.33%
Average cost of electricity (% of total cost)	6.29%	9.04%	7.43%
By firm size			
Large (100 employees and over)			
Number of firms	5,173	4,212	9,385
Percentage of firms quoting electricity as a major or severe constraint	21.95%	21.90%	21.93%
Average number of power outages	29.96	27.35	28.79
Percentage of firms with a generator	46.69%	61.46%	52.65%
Average cost of electricity (% of total cost)	4.99%	7.49%	5.99%
Medium (20-99 employees)			
Number of firms	6,942	6,276	13,218
Percentage of firms quoting electricity as a major or severe constraint	19.10%	19.47%	19.28%
Average number of power outages	21.65	25.33	23.40
Percentage of firms with a generator	27.30%	40.05%	32.62%
Average cost of electricity (% of total cost)	6.33%	9.38%	7.62%
Small (<20 employees)			
Number of firms	7,949	10,163	18,112
Percentage of firms quoting electricity as a major or severe constraint	16.51%	11.13%	13.50%
Average number of power outages	18.92	20.13	19.60
Percentage of firms with a generator	15.31%	22.15%	17.92%
Average cost of electricity (% of total cost)	7.91%	10.41%	8.94%

Source: Authors' analysis based on data described in the text

In column 4, we add the electricity-intensive sector dummy, and in column 5, we introduce its interaction term with outages, which, as expected, turns out to be negative. Thus, the net marginal impact of outages is approximately two-thirds lower in electricity-intensive sectors. This lower impact illustrates the result from proposition 1, according to which firms in these sectors only operate in the presence of outages if they are able to invest in a generator. Therefore, the probability that they will make such an investment is not marginally affected by the number of outages. Note also that in both columns, the coefficient for S_b is large, positive, and significant. Indeed, as emphasized in the model, firms in these sectors are much more likely to own a generator at the baseline because even a small number of interruptions can have very disruptive effects.

Columns 6 and 7 present robustness checks. A standard concern is the potential endogeneity of measures of exposure to power outages. Several effects

TABLE 4. Remedial Capital Ownership

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
				Full Sample			
Probit (marginal effects reported)	Generator	Generator	Generator	Generator	Generator	Generator *Avg. nb of outages*	Generator *Alternative S_h*
Number of power outages (log)	0.03	0.034	0.019	0.019	0.026	0.042	0.026
	(11.71)***	(12.08)***	(6.60)***	(6.27)***	(4.51)***	(1.13)	(4.49)***
Sectors highly reliant on electricity S_h				0.131	0.159	0.18	0.158
				(2.46)**	(2.50)**	(2.15)**	(2.48)**
Number of power outages (log) * S_h					−0.017	−0.046	−0.017
					(2.25)**	(1.81)*	(2.15)**
Firm size dummies		Yes	Yes	Yes	Yes	Yes	Yes
Other firm characteristics		Yes	Yes	Yes	Yes	Yes	Yes
Measures of financial constraints			Yes	Yes	Yes	Yes	Yes
Country dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Industry dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	24,943	18,786	12,704	12,240	12,240	15,384	12,240

Source: Authors' analysis based on data described in the text.

Note: Absolute value of z statistics in parentheses. Standard errors are clustered at the industry level.

* significant at 10%; ** significant at 5%; *** significant at 1%.

TABLE 5. Firm Size Distribution as a Function of Power Outages

	(1) Number of firms <10 / total number of firms (by industry-country) OLS	(2) Number of firms <20 / total number of firms (by industry-country) OLS	(3) Number of firms <20 / total number of firms (by industry-country) OLS	(4) Number of firms <20 / total number of firms (by industry-country) OLS *Alternative* S_b	(5) Number of firms <20 / total number of firms (by industry-country) OLS *Alternative* S_b
S_b	0.030	0.044	0.046	0.033	0.038
	(1.91)*	(2.79)***	(3.00)***	(2.38)**	(2.66)***
C_b	−0.039	0.042	0.047	0.047	0.053
	(1.39)	(1.42)	(1.45)	(1.57)	(1.68)*
$S_b * C_b$	−0.016	−0.045	−0.047	−0.056	−0.062
	(0.66)	(1.68)*	(1.74)*	(2.21)**	(2.47)**
N_{jc}			−0.008		−0.008
			(0.21)		(0.22)
R^2	0.01	0.00	0.00	0.00	0.00
Observations	1,805	1,805	1,777	1,805	1,777

Source: Authors' analysis based on data described in the text.

Note: Robust z statistics in parentheses; standard errors are clustered at the country level.

* significant at 10%; ** significant at 5%; *** significant at 1%.

may interact, including endogenous location by firms, endogenous placement of electricity distribution lines, nonrandom outages depending on the geographical and seasonal needs of different industries, and possibly different propensities to report outages depending on electricity dependence. Note that, as reported in table 2 above, the fact that no firm characteristic, including location, explains reported outages significantly reduces the scope of these potential problems. In any case, addressing endogeneity in this context is difficult. In column 6, we follow standard practices and replace the outage variable by the average number of outages in the corresponding industry-country cell.[18] Although, unsurprisingly, significance is slightly reduced, our main result holds. In column 7, we use the alternative classification of electricity-intensive industries defined in the discussion of table 4 above. Again, the results are very similar to those in column 5.

Next, we turn to the analysis of firm size distribution using difference-in-differences estimates. Note that there are unobserved characteristics at both the sector and country levels that affect our variables of interest. For example, the number of small firms is always higher in sectors that are heavily reliant on electricity than in other sectors (49.21 percent versus 39.62 percent; see table 3). Similarly, high-outage countries are poorer on average and thus may have different proportions of small firms. Taking the double difference across countries and sectors allows us to control for these unobserved characteristics.[19]

Figure 3 illustrates our results. It depicts the differences-in-differences, as in (7), by size brackets, using the industry-country ratio of the number of firms in a given category (by the interval of 10 employees: strictly less than 10, between 10 and 19, and so forth) to the total number of firms as the dependent variable. The resulting coefficients capture variations in the ratio between these two groups of countries ($C_h = 1$ and $C_h = 0$, those above or below the median number of outages by countries in the full sample, respectively; equal to 7.9) and two types of sectors ($S_h = 1$ and $S_h = 0$).[20] Figure 3 shows a relatively larger decrease in the proportion of small firms in electricity-intensive sectors in high-outage countries, with a significant 3 percent reduction for firms of 10 to 20 employees. The relative proportions remain constant or increase for most other upper categories, significantly so for the 45 to 50 employee category.

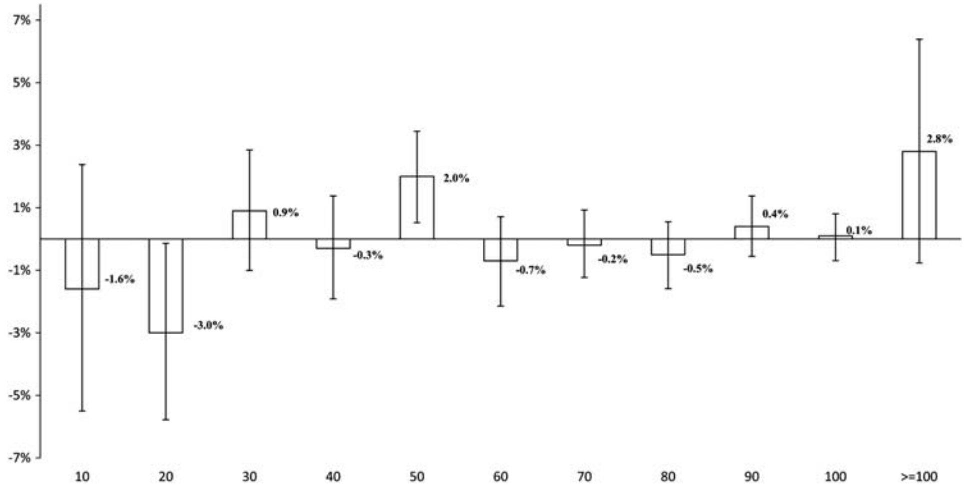
Table 5 presents the regression-based difference-in-differences estimates, as in (7). Our dependent variable Z_{jc} is the industry-country ratio of small (alternatively, less than 10 and 20 employees) to total firms. In columns 1 and 2, we find, as expected, that the difference-in-differences estimator ($S_h{}^*C_h$) is negative,

18. See Dethier, Hirn, and Straub (2011).

19. A more difficult issue arises if, for example, there are systematic measurement errors in the measure of small firms that are correlated with these unobserved effects. We discuss these issues in section 6 below.

20. Using the average number of outages (11.56) as the threshold instead yields very similar results.

FIGURE 3. Change in Firm Size Distribution as a Function of Grid Efficiency



Note: The vertical lines show 90% confidence intervals.

although it is only significant when considering firms of 20 employees or less. In column 3, we add the average number of outages by industry-country cells (N_{jc}) to better control for industry-country-level variations in exposure to outages. Adding this variable enhances the significance of the difference-in-differences estimator. Finally, in columns 4 and 5, estimates using the alternative S_b classification are even larger and are significant at the 5-percent level. Overall, the marginal effect of the interaction terms corresponds to a reduction in the mean of the share of firms with less than 20 employees of between 3.1 and 4.3 percent. This share corresponds to roughly 2,000 firms in our overall sample.

The results in this section are mostly descriptive in nature, and we must be careful about any causal interpretation. The next section briefly discusses some limitations and robustness issues that arise from the nature of the data.

ROBUSTNESS ISSUES AND DISCUSSION

A standard concern with firm surveys is potential nonresponse bias because some firms may not respond to specific questions. The survey's sample frames are derived from the universe of eligible firms obtained from countries' statistical offices or related agencies, and the survey targets formal (i.e., registered) private companies with five or more employees in the manufacturing and services sectors. The methodology follows a stratified random sampling with replacement, where the strata are firm size (5-19 (small), 20-99 (medium), and 100+ employees (large-sized firms)), business sector, and geographic region within a country. Sampling according to firm size ensures a representative sample.[21] In contrast, item nonresponse is more frequent among small and service firms, especially when considering missing data on generator ownership. This item nonresponse is a standard observation in firm surveys, with the main reasons including a lack of time and/or information on the part of the respondent, an issue that is more likely to occur when dealing with small firms. The way that generator ownership is distributed among firm size categories may affect our estimates, even if these nonresponses are not driven by strategic considerations at the firm level. Although we have no systematic way to address this problem, in Alby, Dethier, and Straub (2010), we report that most of the conclusions in table 4 are robust to excluding small firms and all service activities, respectively.

A more general issue is the fact that surveys cannot provide information on firms that were not available as a result of credit constraints or an unreliable public power supply. Dethier, Hirn, and Straub (2011) address this "camels and hippos" self-selection issue in detail, stressing that standard econometric models only provide information about the effect of constraints on the sample of existing firms. However, because self-selection is rarely complete, some informative variation should remain in the data. Our analysis of firm size distribution is a first attempt at addressing the impact of constraints on industry structure.

Another important issue is the role of informal firms. As mentioned above, surveys are limited to formal firms. In that context, we interpret the lower proportion of small firms observed in electricity-dependent industries as a result of power outages as the possible result of a) a reduction in firms' number of employees, perhaps related to technological choices, which may include formal firms falling below the five-employee threshold that defines survey inclusion; b) lower entry, in the sense that some firms simply fail to exist; and c) greater informality, as some of the potential small firms that we do not observe are, in fact, informal. Of course, the data do not allow us to disentangle the relative weight of these factors, but the fact that effects include firms of up to 20 employees suggests that we face a mix of all three channels.

Regarding measurement, it is fair to indicate some limitations of the data. First, some variables are measured in an approximate way. For example, the generator dummy only tells us if an "establishment owns or shares a generator," omitting information on the intensive margin of use. Second, as noted above, there may be measurement errors in the measure of small firms due to item nonresponses or biased sampling. A specific concern would arise if these measurement errors were systematically correlated with sector characteristics, such as dependence on electricity. Such a systematic correlation seems unlikely,

21. Note, however, that sampling weights are not always available for the surveys used in this paper, so we do not use them to ensure a minimum number of observations.

although we cannot completely rule it out. In any case, measurement errors in our dependent variables are likely to induce an attenuation bias.

Finally, to complete the results in this section, we discuss how electricity reliability may affect general investment. In a related paper (Alby and Straub 2011), we provide systematic empirical evidence on the effect of power outages and generator ownership on several categories of investment (machinery and equipment, land and vehicles) across a large sample of firms in 29 low- and middle-income countries and 22 industries at International Standard Industrial Classification level 2. Our results show no impact of generator ownership on overall investment or on any subcategory, but they suggest that when facing more outages, firms without generators invest more than those with generators, an effect driven mostly by investments in land and vehicles.

Our explanation emphasizes investments in land, to secure a safe location where electricity is more reliable, and in vehicles, to support the outsourcing of part of the production process to locations less exposed to electric failures. Finally, we show that general investment is sensitive to firms' intrinsic reliance on electricity, as discussed in the present paper. In non-electricity-intensive sectors, a larger number of firms manage to operate without generators and to adapt their investment strategies to service deficiencies.

Conclusions

The results of our empirical exercise can be summarized as follows. In sectors in which first-best technology relies heavily on electricity, such as the chemical or textile industries, deficient supply induces the largest distortions as firms face a choice between investing in costly generators or settling for second-best technologies, implying large efficiency gaps. For these sectors, a high prevalence of outages affects the returns to investment so severely that most small firms lacking the initial assets to invest in an electric generator are squeezed out of the financial market and unable to borrow to expand production. In these sectors, the probability that firms will invest in a generator depends mostly on their level of initial assets; it is not (or is less) affected by the prevalence of outages. In these sectors, we see a number of large firms with investments in complementary capital (such as power generators) and few small formal firms.

The policy priority to improve performance in sectors with a natural reliance on electricity seems to be to enable access to self-generation. Indeed, at least as long as (close to) full reliability is not obtained, marginal improvements in the quality of the electric supply will have little effect because they will be insufficient to spur small firms' meaningful entry to the market while leaving large firms unaffected. Targeting these sectors with policies that facilitate access to credit through, for example, the provision of credit guarantees or public loans for firms investing in electric generators might have large payoffs if they allow for sector-wide technological adjustments toward the efficiency frontier.

In contrast, in sectors that are less reliant on electricity, the probability of investing in a generator is positively affected by the prevalence of power outages. In addition to a number of large firms with investments in complementary capital, a large range of small firms manage to access the credit market and produce formally despite not having invested in a generator, and their technology is closer to the frontier. For these firms, improvements in the electric supply are likely to have significant positive payoffs.

Both sets of implications could theoretically be addressed by a policy mix that facilitates access to electricity generators for large firms while allowing for the resale of this electricity to surrounding small firms. However, reselling electricity to the grid is not the general practice for enterprises in developing countries. It requires a legislative and/or regulatory enabling framework and, more important, economic incentives for utilities and private firms, which is not automatically the case. The feasibility of such arrangements and the regulatory challenges raised by the evidence uncovered in this paper certainly warrant further work.

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