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Firms Operating under Infrastructure and Credit Constraints in Developing Countries

The Case of Power Generators

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This paper—a product of the Research Support Unit, Development Research Department—is part of a larger effort by the World Bank to use enterprise surveys to identify constraints on productivity and growth in developing countries. Policy Research Working Papers are also posted on the Web at http://econ.worldbank.org. For information, contact jdethier@worldbank.org.

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The Case of Power Generators

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Abstract

Many developing countries are unable to provide their industrial sector with reliable power and many enterprises have to contend with electricity that is insufficient and of poor quality. Because of these constraints, firms in developing countries opt for self-generation even though it is widely considered a second best solution. This paper develops a theoretical model of investment behavior in remedial infrastructure when physical and credit constraints are present. It then tests econometrically some implications from this model using a large sample of enterprises from 87 countries from the World Bank Enterprise Survey Database. After showing that these constraints interact and have non-linear effects depending on the industrial sector's degree of reliance on electricity and size of firms, the paper draws differentiated policy recommendations. Credit constraints appear to be the priority in sectors very reliant on electricity to spur entry and convergence to the technological frontier, while in other sectors, firms would benefit more widely from marginal improvements in electrical supply.

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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

1. Introduction

There is growing evidence, both micro- and macroeconomic, that better electricity infrastructure significantly boosts economic growth and improves a range of development outcomes.[4] Energy is necessary for the operation of productive capital in the industrial sector. Low levels of infrastructure development and poor quality of services can drive up firms' direct and indirect costs and bias their technological choices away from energy-intensive ones which, in turn, increase the overall costs relative to competitors in other regions.[5] Enterprises typically face more barriers in developing countries where firms have difficulties getting connected to the grid from public utilities.[6] When firms do get connected, the sanctioned load is often lower than their demand and they face frequent scheduled and unscheduled power cuts. In addition, fluctuations in voltage and frequency of power supplied causes machine damage, material losses, and variations in product quality. As a result, production volumes, manufacturing costs and output quality are all adversely affected; firms invest less or in less efficient technologies and have lower productivity growth.

To offset these negative impacts, industrial firms in developing countries are often opting for self-generation 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% of the installed generating capacity in 3 countries, and for more than 10% in 9 others. This of course has a negative impact on their overall investment capacity: In Nigeria, where 40% of electricity consumed is produced through auto-generation, firms spend up to 20–30% of initial investment on measures to enhance the reliability of electricity supply.[7] It also drives up costs: Foster and Steinbucks (2009) estimate that in Africa, own-generated electricity is on average 313% more expensive than that from the grid. In environments with important credit constraints, such investments in mitigating

[4] See for example Calderón and Servén (2003), and Calderón (2009) for cross-country estimations, and Dinkelman (2009) and Lipscomb, Mobarak and Barham (2009) for microeconomic evidence.
[5] Eifert, Gelb and Ramachandran (2008).
[6] World Bank (2005); Bartelsman, Haltiwanger and Scarpetta (2004).
[7] Adenikinju (2005).

technologies are often inaccessible to smaller firms or those more severely exposed to credit restrictions. Infrastructure failures and credit limitations therefore interact in constraining firms' development, both by making existing investments less productive and by discouraging new ones.

In this paper, we use a sample of 46,606 firms across 87 countries covering the period 2002-2006 to analyze the behavior of firms facing both infrastructure and financing constraints. In particular, our objective is to understand under which conditions they decide to invest in their own generating capacity, and how this decision is affected by the above mentioned constraints and their interactions with firm- and sector-level characteristics. The answers to these questions are important because they condition the policies towards industrial development and, in particular, the way policy makers in different environments should prioritize measures related to credit limitations versus those addressing investment in infrastructure.

A number of papers have documented the burden imposed on developing countries' firms by an erratic, low quality supply of electricity. Early contributions include Lee, Anas and Oh (1996) and Lee, Anas, Verma and Murray (1996)—both of which use data from Nigeria, Indonesia and Thailand. Lee, Anas and Oh (1996) document the extent and incidence of public infrastructure deficiencies, the response of private entrepreneurs in terms of investment in private infrastructure and the private cost of generation. They conclude that the private costs of infrastructure deficiencies are substantial and that the burdens fall disproportionately on smaller firms, while pointing out large differences across these three countries, linked in particular to the regulatory environment. In Indonesia and Thailand, the opening up of infrastructure markets to private providers and the possibility of shared production appears to ease constraints on all categories of firms and to improve the reliability of service flows.

Lee, Anas, Verma and Murray (1996) develop a model of the firm in which electricity is produced internally, with scale economies to explain why firms supplement their purchases of publicly produced electricity with electricity produced internally (a practice that is prevalent in Nigeria, common in Indonesia, but rare in Thailand). The paper confirms strong scale economies in internal power production in both Nigeria and Indonesia and establishes that in both countries, smaller firms would be ready to pay higher prices for reliable public power than larger firms. It therefore concludes that instead of giving quantity discounts, public monopolies could reallocate scarce resources by charging the larger firms more and the smaller firms less than they presently do. In Nigeria, the large firms would make intensive use of their idle generating capacity, while in Indonesia they would expand their facilities. In both countries, small users would realize savings by having to rely less on an expensive power generator.

Hallward-Driemeier and Stewart (2004) document patterns of access to infrastructure services by enterprises in developing countries and show that access varies by infrastructure service and firm size—with electricity often being the biggest problem, and larger firms expressing more concerns than smaller firms about all services. They report that the overwhelming majority of firms in poor countries is affected by electrical outages, leading to losses sometimes exceeding 10% of sales. In Bangladesh, China, Ethiopia, and Pakistan, improvements in the reliability of the power supply is found to increase garment manufacturers' total factor productivity and the growth rates of their output and employment (Dollar, Hallward-Driemeier and Mengistae, 2005). 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. Gulyani argues that self-generation is economical and, combined with power sharing, can serve as a model that could be replicated to ameliorate the power problems plaguing large manufacturing firms in developing countries.

Closest to our paper are contributions by Reinikka and Svensson (2002) and, more recently, by Foster and Steinbucks (2009) and Steinbucks (2008). Reinikka and Svensson analyze a sample of 171 Ugandan firms, some of which responded to poor electricity supply by investing in generators. They show that this came at the cost of reducing overall investment and installing less productive capital. After providing very rich descriptive statistics on in-house electricity generation in 25 Sub-Saharan African countries, Foster and Steinbucks (2009) estimate that the weighted average costs of power own-generation for large firms remains relatively small and that the main victims are both existing informal firms and the formal ones that were not created as a results of the prevailing constraints. They also allude to the potential benefit of allowing firms with generation capacity to resell power into the national grid. Steinbucks (2008) uses firm-level data from Sub-Saharan African countries and concludes that firms experiencing fewer credit constraints are more likely to own a private generator in the areas where public power supply is unreliable.

Our original contribution is to document systematically the effects of both electricity deficiencies and credit constraints on the decision to invest in mitigating technology, i.e., a generator, and to analyze how their impact varies across firm types (in particular, size) and technological characteristics of the industrial sector they belong to. The use of a theoretical model of firms' responses to power outages allows us to derive precise predictions that are borne out by the data. Using a dataset with a wide coverage across 87 countries and 28 two-digit (ISIC) industry classifications, we show that electricity-related constraints have non-linear effects and that they also interact with credit constraints. Moreover, the marginal and threshold effects vary according to sectors' degree of reliance on electricity and firms' size. Finally, we discuss potential policy implications from our results. Credit constraints appear to be the priority in sectors very reliant on electricity to spur entry and convergence to the technological frontier, while in other sectors, firms would benefit more widely from marginal improvements in electrical supply. We discuss how the power-sharing versus pricing policies issues highlighted above may be used to address these implications.

The paper is structured as follows. Section 2 presents our dataset and provides descriptive statistics on the extent of electricity deficiencies and credit constraints, as they emerge from the enterprise surveys. In Section 3, we then develop a model of investment by firms when infrastructure and credit constraints are present. Section 4 spells out the econometric specifications to be estimated with our data. Section 5 presents the results, and Section 6 discusses the policy implications and concludes.

2. Data and Stylized Facts

We use data from the enterprise surveys for 104 countries covered a total of 70,192 firms over the period 2002-2006.[8] Of these, 87 countries have data on number of power outages, 77 countries have data on generator and 34 countries have data on cost of electricity.[9] Table 1 presents general summary statistics, and Table 2 break these down by generator ownership.

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[8] See https://www.enterprisesurveys.org. Unfortunately it is not possible to use the available 2006-09 data for such an exercise since key questions about power were dropped from the questionnaire.

[9] This results in a sample of 62 countries with data on generator and number of power outages, and 32 countries with data on generator, number of power outages and cost of electricity.

Table 1: Summary Statistics for all Firms

	Mean	Median	Minimum	Maximum	S.D	Observations
Number of workers	138.83	22	0	67,598	715.00	70,192
Age of firm	17.27	11	0	261	16.99	69,602
Profit (PPP basis)	2.12e+08	394,000	-4.51e+12	3.70e+12	3.92e+10	22,640
Number of power outage per year	27.57	3	0	7,355	91.08	46,606
Generator Ownership (% of firms with a generator)	31.05	0	0	100	46.27	43,646
Cost of electricity (% total costs)	6.87	3	0	100	13.63	14,256
Investment (PPP basis)	4.75e+07	631.579	-635250	5.92e+11	3.72e+09	41,471
Investment less potential costs of generator (PPP basis)	2.98e+07	6.26	-9.69e+07	2.87e+11	2.40e+09	29,639
% of firms' working capital financed through internal funds	60.73	70	0	100	39.99	66,229
% of firms fully financed through internal funds	38.66	0	0	100	48.70	66,229
% of firms quoting access to finance as severe or major constraint	20.75	0	0	100	40.55	66,811
% of firms quoting electricity as severe or major constraint	15.62	0	0	100	36.31	68,694

Table 2: Summary statistics by ownership of generator

	Owns a generator		Does not own generator	
	Mean	Median	Mean	Median
Number of workers	258.40	55	118.97	21
Age of firm	20.56	15	17.17	12
Profit (PPP basis)	7.73e+08	2.6e+06	7.99e+07	591,166
Number of power outages per year	68.84	12	25.89	5
Percent of Electricity coming from generator	21.35	10.00	-	-
Number of firms	13,553		30,093	

Firms with installed generators are typically larger and report more days without power from the public grid during the survey year. Moreover, such firms are slightly older.

Many developing countries are unable to provide their industrial sector with reliable electric power and industrial enterprises have to contend with electricity that is insufficient and of poor quality.

Table 3 shows the severity of electricity hazards across regions and country income groups. Column 1 reports a subjective indicator: the percentage of firms' managers quoting electricity as major or severe constraint to their operations and growth. Electricity is perceived as a "major" or "very severe" constraint for 15% of the entrepreneurs (and for more than 26% of firms located in low-income countries). The highest percentage of firms considering electricity as a serious problem is in South Asia (43% of firms) followed by East Asia, and Africa. Columns 2 and 3 report objective indicators: the average number of power outages suffered by firms in a given group of countries, and the fraction of them having suffered more than 30 outages in the last year. Overall, firms face period without electricity from the public grid on average 28 times per year but this can be as high as 132 in South Asia and 61 in Africa. In these two regions, close to half of all the firms surveyed experienced more than 30 outages a year.

Table 3: 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 having 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 & 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%

Table 4: Generator ownership and frequency of outages by firm characteristics

		% of firms owning a	Number of power outage		
			With a Generator	Without a Generator	Whole Sample
By firm size	*Number of firms*	*65 597*	*11 164*	*26 459*	*37 623*
	Small	17.4%	55.7	24.7	30.2
	Medium	29.2%	55.8	20.0	31.6
	Large	46.2%	67.4	17.7	43.6
By firm ownership	*Number of firms*	*70 246*	*13 388*	*29 354*	*42 742*
	Domestic	30.2%	73.3	27.4	43.1
	Foreign	39.8%	44.0	17.1	29.0
By firm exporting status	*Number of firms*	*70 350*	*13 115*	*29 294*	*42 409*
	Exporter	44.1%	62.9	19.4	40.2
	Non-Export	27.1%	69.8	27.9	40.7
By firm location	*Number of firms*	*54 869*	*10 516*	*20 920*	*31 436*
	Capital City	35.3%	91.5	35.1	55.9
	No Capital City	32.6%	71.9	25.0	40.8

** 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 three measures provide a consistent picture both across regions and income groups: constraints are more stringent in South Asian, African, Middle-Eastern/North African, and East Asian countries—in that order, and in poorer countries. As a result, many firms invest in a back-up power generator: across countries, 31% of them own one. This peaks to 62% and 37% in South Asia and Africa respectively.

Looking now at firms' characteristics, Table 4 shows that firms that are large (in terms of number of employees, with similar conclusions if considering sales, investment, or capital), foreign-owned, exporting, and based in the capital-city report owning a generator more often.

Finally, Table 5 provides information on access by firms to the credit market. Interestingly, most "objective" measures of credit constraints indicate that small firms are suffering more than their larger counterparts, while perceived constraints are more stringent for medium firms. When disaggregating by generator ownership and perception of electricity constraints, respectively, firms without generator and firms suffering from electricity constraints appear to be more concerned with access and cost of finance.

Table 5: Credit constraints by firm characteristics

	% of firms quoting Access to finance as severe or major constraint	% of firms quoting Cost of finance as severe or major constraint	% of firms' working capital financed through internal funds	% of firms' new investment financed through internal funds	% of firms with 100% of working capital financed through internal funds	% of firms with 100% of new investment financed through internal funds
By firm size						
Small	19,3%	31,4%	68,4%	54,2%	47,4%	44,6%
Medium	22,7%	36,3%	58,2%	50,8%	35,2%	38,1%
Large	19,9%	31,2%	53,4%	49,8%	30,3%	35,2%
By generator ownership						
With generator	23.3%	35.1%	53.5%	50.7%	30.0%	37.0%
Without generator	26.2%	40.4%	56.1%	44.2%	35.4%	34.0%
By perceived severity of electricity constraint						
Major or severe	40.1%	47.4%	59.1%	57.5%	37.5%	42.3%
Mild	17.1%	28.5%	62.6%	52.1%	39.8%	40.3%
TOTAL	20,7%	32,3%	60,7%	51,7%	38,7%	39,7%

The next section develops a theoretical model of firm-level investment in remedial infrastructure in the presence of electricity and credit constraints.

3. The Model

We consider a continuous moral hazard investment model à la Holmstrom and Tirole (1997). Entrepreneurs are endowed with assets A, which can be for example cash or some productive assets they can pledge as collateral, distributed over a range $[0,A_H]$. To undertake a productive project of variable size I, they intend to borrow an amount $I - A$. This project yields RI 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, while if he shirks, it is only $p_L < p_H$, but he enjoys a private benefit BI or equivalently saves on the cost of effort.

To be socially valuable, it must be the case that the net present value (NPV) per unit of investment is positive if effort is exerted ($p_H R > 1$) and negative if not ($p_L R + B < 1$). The credit contract then consists in an amount I and shares corresponding to the borrower (R_b) and the lender (R_l), such that $RI = R_b + R_l$. The incentive constraint of the borrower is given by:

$$p_H R_b \geq p_L R_b + BI \quad \Leftrightarrow \quad R_b \geq BI/\Delta p, \tag{1}$$

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

$$p_H R_l \geq I - A. \tag{2}$$

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

$$I \leq kA, \tag{3}$$

where $k = 1/[1+(p_H B/\Delta p) - p_H R]$. In a competitive credit market, borrowers get all the surplus, which can be written as $U_b(A) = (p_H R - 1)I = (p_H R - 1)kA$, and they invest the maximum possible amount ($I = kA$).[10]

Introducing Infrastructure Constraints

Consider now that the net return R to the project also depends on a complementary input, in this case electricity from the grid, the provision of which might be of varying quality. For simplicity, we assume that $R = \delta r$, where r is the gross return absent any infrastructure constraint, and $\delta \in [0, 1]$ is the efficiency of electric supply. This parameter may capture both the quality of electric supply, such as the number of outages affecting the firm, and the sensitivity of the project to electricity supply, which is likely to depend on sectoral

[10] Assumptions (1) and (2) imply that $k > 1$. We also need to assume that $p_H R < 1 + p_H B/\Delta p$ to ensure that the optimal size of the firm is not infinite.

characteristics such as the degree to which a specific productive process relies on electricity as an input.

The first question is whether the project is still worth undertaking. If $p_H\delta r < 1$, the unit NPV is too low and production simply does not occur. This defines a threshold value of δ, denoted $\delta_0 \equiv 1/p_H r$, under which entry will not happen. The quality of supply and the sector-level sensitivity interact 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. Define S_i as the sector-level benchmark electricity intensity, such that a sector with a higher "sensitivity to electricity" have a higher S_i. The model's assumption is that the higher S_i, the lower the number of power outages N such that $\delta < \delta_0$.

As long as $p_H\delta r > 1$, the problem is solved as above and entrepreneurs invest $I \leq k^\delta A$, where:

$$k^\delta = 1 / [1 + (p_H B/\Delta p) - p_H\delta r]. \quad (4)$$

Their final utility is given by:

$$U_b(A) = (p_H\delta r - 1)\, k^\delta A. \quad (5)$$

Alternatively, when the cost of infrastructure deficiencies is too high, the firm can obtain a higher return by investing in private substitutes capital goods, for example a diesel generator in the case of electricity. This investment has a cost κ, leaving the firm with an initial capital $A - \kappa$, but the firm then ensures a return R^G, such that $\delta r < R^G < r$. In that case, the firm proceeds to invest $I^G = k^G(A - \kappa)$, where:

$$k^G = 1 / [1 + p_H B/\Delta p - p_H R^G]. \quad (6)$$

The firm gets utility:

$$U^G_b(A) = (p_H R^G - 1)\, k^G(A - \kappa). \quad (7)$$

Optimal Firm Decision

Let us now compare the benefits from investing or not in a generator at different levels of wealth A. It is straightforward to see that $k^G > k^\delta$. From the expressions of $U_b(A)$ and $U^G_b(A)$, we can draw figures 1 and 2.

Figure 1 represents the case in which $\delta < \delta_0$. In this parameter space, we obtain a stark outcome: firms above a cutoff level A_L invest in complementary capital, take credit and enter production, while firms below the cutoff are credit constrained, as infrastructure deficiencies are so stringent that the return from production is too low to access the credit market, and they lack the capacity to invest in a generator. Notably, A_L does not depend on δ as long as $\delta \leq \delta_0$. Although this is not modeled formally here, one can imagine that these potential entrepreneurs remain in the informal sector and consume their own endowments.

Figure 2 represents the case in which $\delta > \delta_0$. In that case, two types of investment behavior coexist. Below the cutoff level A^*, firms do not invest in generators but are still able to obtain credit and enter production, while above the threshold large firms invest in generators and obtain a higher leverage in the credit market. When power from the grid is more reliable, entry to the productive sector becomes profitable across the range of potential entrepreneurs and sectors. Again a duality exists in terms of access to remedial investments and therefore productivity, but in contrast to the previous case, A^* is increasing in δ, meaning that as long as $\delta > \delta_0$, an increase in power cuts will trigger additional investments in generators.

The following proposition summarizes the main results so far.[11]

Proposition 1

1. *There is a threshold δ_0 such that $\partial A^*/\partial\delta > 0$ if and only if $\delta \geq \delta_0$*, while for $\delta < \delta_0$, $\partial A^*/\partial\delta = 0$.
2. *The number of power outages N_j such that $\delta < \delta_0$ is decreasing in S_i, the benchmark electricity intensity of the sector: $\partial N_j/\partial S_i < 0$.*

[11] Most proofs are straightforward and are therefore omitted. An appendix with the formal derivation of the comparative statics results is available upon request.

Figure 1 ***(δ < δ₀)***

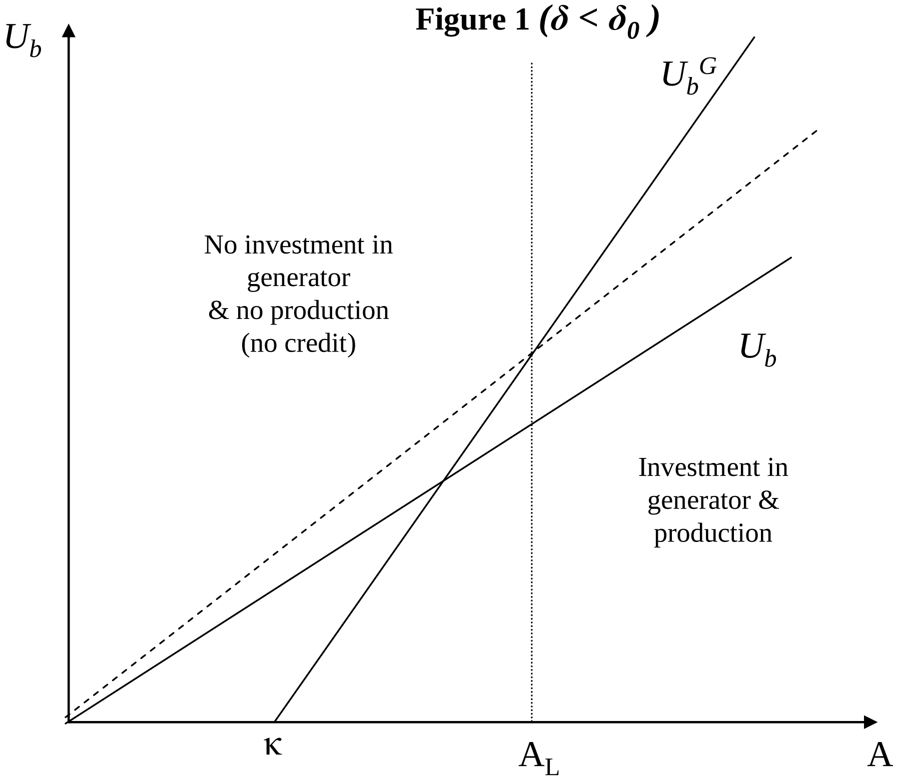
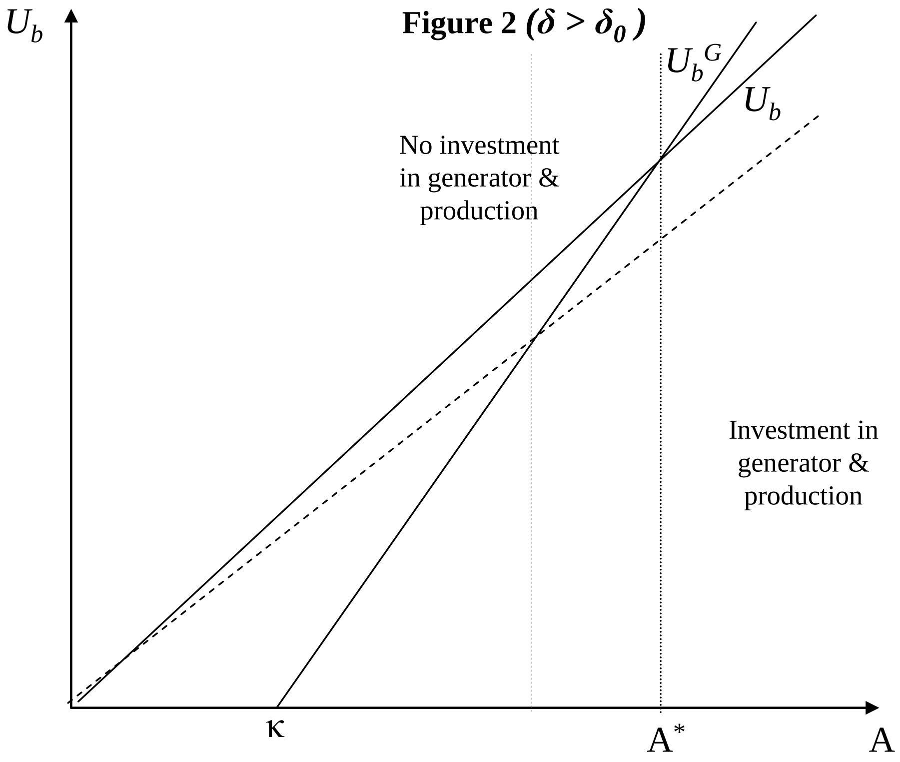


Figure 2 ***(δ > δ₀)***



Proposition 1 first states that the propensity to own a generator increases in the number of outages until these reach an upper threshold (above which $\delta < \delta_0$), above which there is no effect as investment is discouraged altogether. The second item establishes that this threshold is lower in sectors naturally reliant on electricity, so entry is discouraged more easily.

The following corollary derives implications in terms of firm size:

Corollary 1 *For small firms ($A \leq A_L$), changes in the number of power outages have no effect on the level of initial assets A* above which the firm finds it profitable to invest in a generator. This effect is negative for larger firms ($A \geq A_L$) and the marginal effect is increasing in S_i, the benchmark electricity intensity of the sector.*

Corollary 1 states that the two extremes of firms' size distribution are unaffected by outages: firms smaller than A_L always lack the capacity to invest in a generator, while very large ones systematically do so. It is in the range of mid-size firms that growing electricity problems induce additional investments in generators.

Finally, the trade-offs above are also affected by the effect of credit constraints. Environments plagued by more moral hazard will have less well functioning credit markets. A simple way to characterize this in the model is to consider variations in *B*, which is the private benefit to shirking borrowers.[12] Looking at the effect of variations in *B* on the cutoff level *A**, it appears that dysfunctional credit markets bite harder in environments with strong infrastructure constraints, in the sense that their marginal effect on the asset threshold above which firms are able to access substitute capital goods is stronger in that context.

Proposition 2 *The minimum level of initial assets A* above which the firm finds it profitable to invest in a generator is increasing in the extent of financial constraints, and this effect is stronger for $\delta < \delta_0$, i.e., $\partial A^*/\partial B > 0$, and $\partial A^*/\partial B|_{\delta < \delta_0} > \partial A^*/\partial B|_{\delta \geq \delta_0}$.*

Proposition 2 states that credit constraints are an important limitation on firms' ability to escape from electricity problems. As access to credit worsens, a range of mid-size firms (those just above A_L) are prevented from investing in generators. Unsurprisingly, this is more

[12] Alternatively, one could consider that lenders recoup only a fraction of their loan, for example because of failures in the justice system, as in Straub (2005), and let this parameter vary. Qualitative results would be similar.

acute at high levels of electricity deficiencies. This can be seen easily in Figure 1: as U_b^G shifts to the right (maintaining the origin fixed), A_L goes up and the area in which firms are unable to enter production expands to the right. On the other hand in Figure 2, i.e., for $\delta > \delta_0$, this effect is dampened by the fact that U_b also shifts to the right, so the net effect is smaller. Proposition 2 also implies that the effect of credit constraints is more pronounced in sectors naturally reliant on electricity, in the sense that their marginal effect increases faster and at a lower level of outages.

4. Econometric Specifications

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

$$Gen_{ijc} = 1[Gen^{*}= \theta_j + \theta_c + \theta_t + \alpha_1\delta_{ijc} + \alpha_2\delta_{ijc}^2 + \alpha_3F_{ijc} + \alpha_4F_{ijc}{*}\delta_{ijc} + X_{ijc}\,\gamma + \varepsilon_{ijc} > 0], \quad (8)$$

where $1[.]$ is an indicator function equal to 1 if the statement in brackets is true, i indexes firms, *Gen* is a binary variable equal to 1 if the firm owns a generator and 0 otherwise, the θ*'s* are fixed effects for industries (j), countries (c), and years (t), δ_{ijc} is a measure of the number of power outages facing the firm, F_{ijc} is a measure of financial constraint facing the firm, and X_{ijc} is a vector of firm-level controls.

The quadratic term is meant to capture in a very generic fashion the non-linear effects of power outages, and we expect $\alpha_1 > 0$ and $\alpha_2 < 0$, i.e., the probability of owning a generator is increasing in the prevalence of outages but above a given threshold (corresponding to δ_0 in the model), their effect vanishes. On the other hand, the interaction between outages and financial constraints allows us to test whether these indeed matter and whether they are felt more strongly when outages are very prevalent; in this case, we expect $\alpha_3 < 0$ and $\alpha_4 < 0$.

The model also implies that the coefficients should differ according to the intrinsic sensitivity of different sectors to the quality of electric supply. An important question is how to define this last aspect. We define S_i as a measure of electricity expenditure as a percentage of total cost. To simplify further the empirical test, we define S_0 as a dummy variable equal to 1 for sectors which rely importantly on electricity as an input and 0 otherwise.

To mitigate potential worries linked to the fact that technology choice is to some extent endogenous, so that industries in environments with a lot of outages may substitute towards technologies that use less electricity, the sector-level benchmark value is defined taking reference values from countries with relatively low electricity constraints.[13] The underlying logic is to have a reference value of what technological choices would look like in a distortion-free environment, akin to a sector technological frontier. We do not need to assume that technological choices will be the same in the presence of electricity deficiencies, but rather that in sectors in which the first-best technology would be very electricity intensive the impact of deficiencies will be stronger and will penalize firms more heavily, as those not owning generators will have to settle for second-best technologies implying a larger efficiency gap. We discuss the technical details of the variable construction further in the next section.

Equipped with this measure of "benchmark electricity intensity", we can then test (8) on the two subsamples corresponding respectively to $S_0 = 0$ and $S_0 = 1$. From the model, we expect the cutoff level, above which the effect of outages vanishes, to be lower in the second subsample, and similarly for the cutoff above which financial constraints bite harder.

5. Empirical Analysis

In order to estimate the specification above, we need to construct the parameter S_0. The countries in our sample which have the smallest number of power outages are Indonesia, Lithuania, Brazil, Poland and Thailand. Within this subsample, we compute the average cost of electricity as a percentage of total cost by industrial sector, as shown in Table 6.[14] We classify as "very reliant on electricity" ($S_0=1$) the industrial sectors that are above the median (7.65 percent), and the rest as sectors not relying too much on electricity ($S_0=0$). Since all industrial sectors are not represented in our subsample of five countries with reliable

[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), Fisman and Sarria-Allende (2004) and Sharma (2007).

[14] A more satisfactory method would have been to use as a reference the average cost of electricity as a share of total cost by industrial sector for some industrialized country. However, such data does not appear to be readily available.

Table 6: Reliance on electricity in countries with reliable service, by industrial sector

INDUSTRIAL SECTOR	Cost of Electricity (% of total cost)	Number of firms having non zero electricity cost
Other services	2,21	1
Metals and machinery	3,50	352
Leather	4,07	161
Garments	4,44	759
Auto and auto components	5,61	280
Agroindustry	5,70	17
Electronics	5,94	266
Non-metallic and plastic materials	6,30	234
Wood and furniture	6,93	495
Construction	7,58	18
Other unclassified	7,72	8
Food	8,59	474
Transport	11,08	11
Chemicals and pharmaceutics	11,47	153
Textiles	11,89	510
Paper	12,40	28
Retail and wholesale trade	13,31	2
Other transport equipment	21,86	18
Real estate and rental services	24,49	1
Beverages	30,49	16
Overall Total	**7,07**	**3804**

Note: The countries with the least number of power outages in our sample are Lithuania, Thailand, Poland, Indonesia and Brazil.

Table 7: Firm sub-samples according to S_0

	S_0		
By firms size	0	1	TOTAL
Large (100 and over)			
Number of firms	8873	6211	15084
% of firms quoting Electricity as a major or severe constraint	19,81%	18,72%	19,34%
Average Number of power outage	29,96	27,35	28,79
% of firms with a generator	40,11%	57,03%	46,43%
Average Cost of Electricity (% of total cost)	4,77	7,22	5,76
Medium (20-99)			
Number of firms	11628	9869	21497
% of firms quoting Electricity as a major or severe constraint	15,39%	15,27%	15,34%
Average Number of power outage	21,65	25,33	23,40
% of firms with a generator	24,86%	35,23%	29,17%
Average Cost of Electricity (% of total cost)	5,85	8,95	7,16
Small (<20)			
Number of firms	13326	15021	28347
% of firms quoting Electricity as a major or severe constraint	13,15%	9,50%	11,21%
Average Number of power outage	18,92	20,13	19,60
% of firms with a generator	16,55%	18,97%	17,49%
Average Cost of Electricity (% of total cost)	6,85	9,05	7,70
Entire Sample			
Number of firms	33827	31101	64928
% of firms quoting Electricity as a major or severe constraint	15,57%	13,16%	14,39%
Average Number of power outage	22,71	23,18	22,95
% of firms with a generator	26,19%	35,21%	29,74%
Average Cost of Electricity (% of total cost)	5,82	8,44	6,88

electricity services, we assign a value for S_0 in eight missing industrial sectors following intuitive criteria.[15] Table 7 presents some summary statistics on these two subsamples of firms.

One standard worry with firm surveys is the potential non-response bias, as some firms may not respond to specific questions. Overall, non-response is more frequent among small and service firms, and this is also the case when looking at missing data on generator ownership. This is a standard observation in firm surveys, the main reasons including lack of time and/or information by the respondant—a situation more likely to occur in small firms. Because of the way generator ownership is distributed among firm size categories, this may affect our estimates, even if these non-responses are not driven by strategic considerations at the firm-level. While we have no systematic way to address this problem, results not shown here to save space indicate that most of our conclusions below are robust to excluding small firms and all service activities respectively.[16]

The results from estimating equation (8) are shown in Table 8. All specifications include country, industry and year fixed effects, and standard errors are clustered at the country-industry level. We introduce in columns 1 and 2 the number of power outages and its square. Column 1 reports the results with only fixed effects, while column 2 introduces firm-level controls (age of firm, location, whether it exports or not, whether it has foreign capital or not, and 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. The square value of the number of outages should be negative to match the concavity stressed in the theoretical model, and indeed we find that its coefficients are negative and significant in both columns. The threshold values indicated below mean that

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[15] A "core" set of sectors is systematically included in all country surveys so that the missing ones represent relatively few firms overall. (See Dethier, Hirn and Straub 2010, for a detailed description of the surveys). We consider Sports Goods, Other manufacturing, and Mining and quarrying as industrial sectors that do not rely heavily on electricity (the cost share of electricity in these sectors is less than 3.5 percent in the full sample of countries) and assign to these sectors, as well as to Accounting and finance and Advertising and marketing a value of $S_0=0$. Symmetrically, we assign a value $S_0=1$ for firms operating in IT services, Hotels and restaurant, and telecommunications (average cost share of electricity above 8.6 percent in the full sample for the first two).

[16] A more general issue is the fact that surveys cannot provide information on firms that were not born, because of credit constraints or unreliable public power supply. Dethier, Hirn and Straub (2010) address this "camels and hippos" self-selection issue in details, stressing in particular that econometric models like the one in this paper only provide information about the effect of constraints on the sample of existing firms, and that the analysis of entry would require different models. Note however, as pointed out there, that self-selection is hardly ever likely to be complete, so some informative variation should remain in the data.

in the full sample, power outages cease to have an effect on decisions to invest in generators (our δ_0 measure in the model), when they exceed 12 per year.

In columns 3 and 4, we introduce credit constraints, using as proxy a dummy variable indicating if firms quote access to finance as a major or severe constraint. While the findings of columns 1 and 2 are robust to this inclusion, we also find that both credit constraints alone and their interaction with power outages are significant and decrease firms' probability of having invested in complementary capital. In terms of marginal effects, an increase of 1% in the share of financially constrained firms in implies a 0.05% reduction in the probability to have a generator, while facing 10 additional outages per year increases this marginal effect by 6% (since 0.029/100*10/0.048 = 0.060).

Note finally that, in columns 2 and 4, the coefficients of the age, capital city, and particularly export and foreign ownership dummies are large, positive and significant, while their inclusion actually reinforces the effects of power outages and credit constraints.

Table 8: Complementary Capital Decision

	(1)	(2)	(3)	(4)
Probit	Generator	Generator	Generator	Generator
Number of Power Outage (/100)	0.120	0.172	0.146	0.206
	(3.39)***	(5.10)***	(4.16)***	(6.70)***
Number of Power Outage (/100) Square	-0.002	-0.006	-0.002	-0.007
	(2.74)***	(3.62)***	(3.31)***	(4.61)***
Access to Credit is Major/Severe Constraint (dummy)			-0.193	-0.136
			(6.46)***	(4.16)***
Access to Credit is Major/Severe Constraint (dummy) *			-0.064	-0.082
Number of Power Outage (/100)			(3.13)***	(2.90)***
Age		0.005		0.005
		(3.84)***		(3.67)***
Capital City dummy		0.106		0.116
		(2.06)**		(2.24)**
Export dummy		0.372		0.368
		(7.86)***		(7.70)***
Foreign dummy		0.216		0.212
		(4.92)***		(4.77)***
Constant	-0.313	-0.717	-0.336	-0.155
	(1.41)	(2.63)***	(1.54)	(0.56)
Firm Size dummies		Yes		Yes
Country dummies	Yes	Yes	Yes	Yes
Industry dummies	Yes	Yes	Yes	Yes
Year dummies	Yes	Yes	Yes	Yes
Observations	24 943	18 786	23 953	18 017
Threshold value $\delta= -\alpha1/2\alpha2$	22.00	15.25	26.50	12.17

Absolute value of z statistics in parentheses, standard errors are clustered at the country-industry level.
* significant at 10%; ** significant at 5%; *** significant at 1%

Next, in Table 9, we present the same specifications as in Table 8 but on the two subsamples corresponding respectively to $S_0=0$ (columns 1 to 4) and $S_0=1$ (columns 5 to 8). As we can see, while there are no major qualitative differences between the results obtained in the two subsamples, the size of the coefficients vary.

Table 9: Complementary Capital Decision depending on Sector Reliance on Electricity

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	$S_0=0$	$S_0=0$	$S_0=0$	$S_0=0$	$S_0=1$	$S_0=1$	$S_0=1$	$S_0=1$
Probit	Generator	Generator	Generator	Generator	Generator	Generator	Generator	Generator
Number of Power Outage (/100)	0.103	0.165	0.129	0.200	0.194	0.281	0.207	0.283
	(2.68)***	(4.04)***	(3.48)***	(5.83)***	(4.61)***	(4.40)***	(3.91)***	(4.18)***
Number of Power Outage (/100) Square	-0.001	-0.006	-0.002	-0.007	-0.007	-0.030	-0.008	-0.030
	(2.16)**	(3.10)***	(2.74)***	(4.22)***	(2.90)***	(3.45)***	(2.82)***	(3.14)***
Access to Credit is Major/Severe Constraint (dummy)			-0.215	-0.125			-0.206	-0.210
			(6.13)***	(3.19)***			(4.73)***	(4.99)***
Access to Credit is Major/Severe Constraint (dummy) * Number of Power Outage (/100)			-0.075	-0.100			-0.018	0.011
			(4.13)***	(3.08)***			(0.34)	(0.27)
Age		0.005		0.005		0.006		0.006
		(3.87)***		(3.63)***		(4.42)***		(4.26)***
Capital City dummy		0.141		0.147		0.061		0.073
		(2.05)**		(2.13)**		(0.73)		(0.85)
Export dummy		0.440		0.435		0.226		0.232
		(6.74)***		(6.54)***		(3.23)***		(3.35)***
Foreign dummy		0.178		0.173		0.278		0.263
		(3.39)***		(3.22)***		(3.82)***		(3.47)***
Constant	-1.439	-1.372	-0.770	-0.950	-0.630	-0.330	-0.846	-0.181
	(5.59)***	(4.13)***	(3.29)***	(3.02)***	(3.49)***	(0.74)	(1.51)	(0.40)
Firm Size dummies		Yes		Yes		Yes		Yes
Country dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Industry dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	13 907	10 511	13 327	10 072	10 544	7 806	10 134	7 476
Threshold value δ= -α1/2α2	17,50	13,00	22,00	16,00	12,50	4,91	13,33	4,95

Absolute value of z statistics in parentheses, standard errors are clustered at the country-industry level.
* significant at 10%; ** significant at 5%; *** significant at 1%

The main model's prediction is that the cutoff level—above which the effect of outages vanishes—should be lower in the subsample of electricity-intensive sectors ($S_0=1$). The threshold levels computed with the marginal values of α_1 and α_2 are indicated at the bottom of Table 10. As expected, they are always lower when firms operate: while power outages effect on the probability to have a generator becomes negative above 16 cuts per year (column 4) in non-electricity intensive sectors, this threshold is reduced to 5 (column 8) in sectors relying heavily on electricity. As mentioned above, this means that, in this latter group, when outages frequency exceeds this relatively low threshold, small firms are virtually unable to operate and the sectors are populated only by large firms owning generators.

Finally, we explore the relevance of the results from corollary 1 above, by estimating equation (8) on different firm size subsamples (respectively small, medium and large firms). We report the results in Table 10. First, note that the number of power outage always significantly increases the probability that small, medium or large firms own complementary capital, although the effect is larger for medium firms. Second, the quadratic term is not significant when considering small firms only, highlighting the fact that the non-linear effect of outages is mostly relevant for medium and, to a lesser extent, large firms. Overall, this confirms our theoretical insight that variations in power outages affect mostly medium-size firms.

Table 10: Complementary Capital Decision and Firm Size

	(1)	(2)	(3)	(4)	(5)	(6)
Probit	Generator	Generator	Generator	Generator	Generator	Generator
	Small Firms Sample		Medium Firms Sample		Large Firms Sample	
Number of Power Outage (/100)	0.243	0.270	0.387	0.389	0.236	0.207
	(1.90)*	(1.84)*	(4.26)***	(3.78)***	(3.53)***	(3.15)***
Number of Power Outage (/100) Square	-0.037	-0.046	-0.068	-0.067	-0.024	-0.023
	(1.02)	(1.14)	(2.79)***	(2.62)***	(3.42)***	(3.49)***
Access to Credit is Major/Severe Constraint (dummy)	-0.078	-0.119	-0.099	-0.121	-0.127	-0.159
	(1.22)	(1.77)*	(2.08)**	(2.12)**	(2.13)**	(2.34)**
Access to Credit is Major/Severe Constraint (dummy) *	-0.011	-0.003	-0.035	-0.021	-0.024	-0.009
Number of Power Outage (/100)	(0.16)	(0.04)	(0.76)	(0.46)	(0.43)	(0.16)
Age		0.005		0.004		0.003
		(2.61)***		(2.30)**		(2.68)***
Capital City dummy		-0.022		0.188		0.147
		(0.30)		(2.39)**		(1.51)
Export dummy		0.267		0.280		0.258
		(2.80)***		(4.54)***		(4.30)***
Foreign dummy		0.426		0.142		0.243
		(4.26)***		(2.06)**		(3.69)***
Constant	-0.453	-0.365	-0.473	-0.939	-1.286	-1.846
	(1.15)	(0.64)	(1.13)	(2.99)***	(2.17)**	(3.15)***
Country dummies	Yes	Yes	Yes	Yes	Yes	Yes
Industry dummies	Yes	Yes	Yes	Yes	Yes	Yes
Year dummies	Yes	Yes	Yes	Yes	Yes	Yes
Observations	6 056	4 375	7 318	5 178	5 317	4 079
Threshold value $\delta = -\alpha 1/2\alpha 2$	3.44	2.95	2.81	2.83	4.70	4.61

Absolute value of z statistics in parentheses, standard errors are clustered at the country-industry level.
* significant at 10%; ** significant at 5%; *** significant at 1%

6. Conclusions and Policy Implications

The results of our empirical exercise can be summarized in an intuitive way as follows. For sectors that are very reliant on electricity, such as the chemical or textile industries, a high prevalence of outages affects returns to investment so badly that small firms that lack enough initial assets to invest in an electric generator end up being squeezed out of the financial market and unable to borrow to expand production. In these sectors, the probability that firms invest in a generator depends mostly on their level of initial assets and is not affected by the prevalence of outages though it is strongly limited by the degree of financial constraints they face. In these sectors, we should see a number of large firms with investments in complementary capital (power generator) and no (or few) small formal firms.

The policy implication hence seems to be that the priority to improve performance in sectors that naturally rely heavily on electricity is to relax financial constraints before addressing physical ones, because firms active in these sectors will have to invest in own generating capacity in order to avoid costly production interruptions and their ability to do so depends primarily on their access to the credit market. On the other hand, as long as full reliability (or close to it) is not obtained, marginal improvements in the quality of electric supply will have little effect since they would be insufficient to spur the entry of small firms to the market, while leaving large firms unaffected.

It is in sectors in which the first-best technology is very reliant on electricity that deficient supply will induce the biggest distortions. Firms there face the choice of investing in costly generators or settling for second-best technologies which imply large efficiency gaps. Targeting these sectors with policies easing the access to credit—for example through the provision of credit guarantees for firms investing in electric generators—might have large payoffs if it allows for sector-wide technological adjustments towards the efficiency frontier.

In contrast, for sectors that are less reliant on electricity, the probability to invest in a generator is positively affected by the prevalence of power outages, and it is again affected by financial constraints, though less strongly than before. We should see, in addition to a number of large firms with investments in complementary capital, a range of small firms that manage to access the credit market and produce formally, despite not having invested in a generator, and whose technology is closer to the frontier. For these firms, improvements in electric supply are likely to have significant positive payoffs.

Both set of implications could theoretically be addressed by a policy mix to relax credit constraints to large firms willing to invest in electricity generator (specific public loans or guarantees, for example) while allowing for the resale of this electricity to small firms around them.[17] However reselling electricity to the grid is not a generalized practice by enterprises in developing countries. It requires a legislative and/or regulatory enabling framework and, more importantly, economic incentives for the utility and the firms, which is not automatically the case.[18] Liberalizing the power market and allowing trade electricity among firms actually reflects coping strategies that many small firms in developing countries would like to adopt. While co-generation (for example, from bagasse by sugar producers) is easier to accommodate because it has a zero marginal cost, it usually involves considerable negotiations because of its seasonality and its uncertainty in terms of volume. Another consideration—highlighting the difficulty of such arrangements—relates to the reason for which firms purchase their generators in the first place. They are either large firms that want to be independent from the grid for economic or security reasons (e.g., refineries or mining companies) and therefore do not have much incentives selling little volume to the grid, or small/medium enterprises which need stand-by generators in case of outages or to ensure high reliability of power supply.

If reselling electricity to the grid is not feasible, a policy of charging different electricity prices for large and small firms is a possibility. As mentioned earlier, there are important scale economies in own power generation so that smaller firms would be willing to pay more for publicly provided power than larger firms. Instead of giving quantity discounts, public monopolies should charge larger firms more and smaller firms less than they presently do. As pointed out by Lee, Anas, Verma and Murray (1996), in countries where large firms have excess capacity like Nigeria, they could make intensive use of their idle power generating capacity, while in countries where firms are expanding like Indonesia, they would enlarge

[17] See the discussion in Lee, Anas and Oh 1996 and in Lee, Anas, Verma and Murray 1996.

[18] Most enterprise-owned generators run on diesel and their marginal cost is much higher than that of large public utilities using fossil fuel-fired power plants, even when there are large line losses.

their facilities. In both types of countries, small users would realize savings by having to rely less on expensive power generators. The evidence uncovered in this paper adds to the rationale of such an approach. However a policy of charging higher tariffs to large industries than to small industries to fully take advantage of the idle capacity of captive power plants in large industries has additional implications which need to be considered. In particular, the cost of supplying electricity to large firms is generally lower than to small firms given the higher voltage level (implying less transmission investments) and the larger electricity volumes supplied. Furthermore, as electricity provided by a network system cannot be provided at different service quality levels to individual customers,[19] the benefit of the proposed pricing policy could take a long time to translate into tangible benefits in terms of improved supply quality for small industries.

Finally, the discussion raises another important issue regarding the environmental impact of different policies. Rather than proposing a general relaxation of financial constraints, it might be more appropriate to shadow price carbon and seek special incentives for renewable energy and/or energy efficiency.[20] Admittedly, it is unrealistic at today's level of technology to achieve good power supply reliability through renewables only. However, the carbon incentive could at least produce benefits in terms of energy consumption and fuel inputs.

[19] Some exceptions might apply to customers belonging to different network "nodes" but it would be a geographical separation that rarely, if ever, coincides with the size of the industry or the consumers served.

[20] We are grateful to Lucio Monari for mentioning this point to us.

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