Outage Duration, Capital, and Firms' Choice between Diesel Generators and Solar in Developing Countries

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Abstract

Unreliable electricity forces firms in developing economies to secure their own power, a need historically met by diesel generators. On-site solar is now cost-competitive with the generator over its lifetime, yet the generator still dominates. I ask whether outage exposure explains the adoption of either technology and, where it does not, what does. I develop a random payoff model of the firm's self-generation choice in which the two technologies differ in two respects. A generator is dispatchable and can be matched to an outage, and the model implies a threshold outage length beyond which running it pays, which makes outage duration rather than frequency the operative margin. Solar without storage follows the sunlight, and its large upfront cost makes adoption depend on firm capability and access to finance rather than on outage exposure. I test these predictions with the 2025 and 2026 World Bank Enterprise Surveys for 11,252 firms in 36 developing economies, with 17 high-income economies as a benchmark. I estimate linear probability and multinomial logit models with country and sector fixed effects and standard

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errors clustered by country, and I report the wild-cluster bootstrap as a robustness check. As a further check on omitted local conditions, measurement error in self-reported outages, and reverse causality, I instrument outage exposure with the outages reported by other firms in the same locality. The findings are as follows. First, generator ownership is associated with outage duration, while outage frequency shows no significant association. Second, the link between outage exposure and solar adoption is small and marginally significant. Third, longer outages raise the probability of holding a generator, on its own or with solar, but not of holding solar only. Fourth, solar adoption tracks firm capability, measured by size, exporting, and digital presence, while bank credit does not predict adoption once capability is controlled for, and firms' assessment of the courts does not change how either technology responds to outages. The paper makes three contributions. It extends the literature on self-generation, which has treated backup power as fossil generation, to the choice between the generator and solar. It identifies outage duration, not frequency, as the margin that drives generator investment. It separates the dispatchability and capital channels, which explains why falling panel prices have not displaced the generator. Firms appear to adopt the two technologies for different purposes, the generator as cover against outages and solar as a capital investment that lowers energy costs. Policies that ease the financing burden of solar would expand clean self-generation, whereas reducing reliance on the generator requires investment in reliable electricity infrastructure.

Keywords: power outages, self-generation, solar adoption, credit constraints, dispatchability, developing economies

JEL: Q42, D22, O13, L94, Q56

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1. Introduction

Unreliable electricity forces firms in developing economies to secure their own power, a need historically met by diesel generators (Steinbuks and Foster, 2010). The economics of self-generation, however, have changed. The installed cost of on-site solar has fallen substantially, making it increasingly competitive with diesel self-generation on a levelised-cost basis (Lam et al., 2019; IRENA, 2024). A comparison of lifetime costs would therefore suggest that firms facing unreliable electricity should increasingly replace generators with solar. Yet generator ownership remains considerably more prevalent. Across 36 developing economies covered by the most recent World Bank Enterprise Surveys, 40.0 percent of firms own a generator, compared with 10.9 percent that use on-site solar. The difference is particularly evident across levels of outage exposure. Generator ownership rises from 24.9 percent among firms reporting no outages to 53.5 percent among those experiencing long outages. Solar adoption, in contrast, increases only from 10.3 to 15.6 percent (Figure 1). Cross-country comparisons reveal a similar pattern, with solar adoption not varying systematically with grid reliability (Figure 2).

This asymmetry may reflect differences in the economic purposes of the two technologies. Generators provide dispatchable backup, allowing firms to maintain electricity supply when the grid fails. Their adoption should therefore respond to outage exposure, particularly the duration of interruptions. Solar without storage, by contrast, depends on sunlight and cannot provide electricity on demand during grid failures. Its economic value may lie primarily in reducing purchases of grid electricity and lowering energy costs over time. However, solar requires a substantial upfront investment, making adoption more dependent on firms'capabilities than on their exposure to

outages. Generators and solar may therefore serve different purposes, with generators protecting firms against interruptions, while solar offers an opportunity to reduce energy expenditure. This distinction matters for policy. Although outages depress output and force firms into costly self-generation (Allcott et al., 2016; Cole et al., 2018), generators remain expensive (Steinbuks and Foster, 2010) and contribute to local air pollution and carbon emissions (Lam et al., 2019).

This paper explores this asymmetry by examining how firms choose between generators and solar, and whether outage exposure explains that choice. It employs a random payoff model to formalise two mechanisms underlying firms' self-generation choices, dispatchability and capital intensity. The first predicts a stronger relationship between outage exposure and generator ownership than between outage exposure and solar adoption. The second predicts that solar adoption is more closely associated with firm capabilities and access to finance than with outage exposure. The empirical analysis uses recent World Bank Enterprise Surveys covering 11,252 firms across 36 developing economies in six regions. It estimates linear probability and multinomial logit models with country and sector fixed effects. A separate benchmark of approximately 9,360 firms across 17 high-income economies is used to examine the determinants of solar adoption. The findings show that generator ownership rises with outage duration, whereas solar adoption is only weakly associated with outage exposure. Longer outages raise the probability of holding a generator, or with solar, but not of holding solar only. Finally, solar adoption rises with firm size, exporting, and digital presence.

This paper makes three contributions. First, it extends the literature on firms' responses to unreliable electricity beyond diesel self-generation

(Reinikka and Svensson, 2002; Steinbuks and Foster, 2010; Oseni and Pollitt, 2015) by examining the adoption of both generators and solar across developing economies. Second, it distinguishes outage duration from frequency, identifying duration as the more relevant dimension of outage exposure for generator ownership. Third, it separates the dispatchability and capital-intensity channels, providing evidence that firms adopt generators and solar for different economic purposes. This distinction helps explain why declining solar costs have not necessarily displaced diesel generators. Section 2 reviews the related literature, Section 3 develops the theoretical model, Section 4 describes the data and empirical strategy, Section 5 presents the results, and Section 6 concludes.

2. Related Literature

2.1. Electricity Unreliability and Firm Performance

A large body of literature establishes unreliable electricity as a first-order constraint on firm performance in developing economies, working through both the price of supply and its reliability. Firm level evidence places indirect costs related to infrastructure and services below 15 percent of total firm costs in stronger-performing developing economies. In most poor African countries, these costs reach 20 to 30 percent, with energy the single largest component (Eifert et al., 2008). Where the constraint has been studied with credible identification, the output consequences are sizeable. Drawing on plausibly exogenous variation in electricity shortages across Indian states, Allcott et al. (2016) show that shortages reduce plant revenues and producer surplus with only modest effects on measured productivity as plants substitute toward stored inputs. Evidence from Chinese industry reveals a

different margin of the same constraint. Fisher-Vanden et al. (2015) find that firms facing greater electricity scarcity re-optimise toward purchased inputs. This raises production costs by about 8 percent while limiting the measured productivity losses they would otherwise bear. The pattern recurs across Africa, where Cole et al. (2018) link outages to lower firm productivity and sales. Mensah (2024) traces the employment consequences of chronic shortages, while firm-level analyses attribute a substantial part of the region's total factor productivity gap to weak infrastructure, including power (Arnold et al., 2008). Related work shows that the price and availability of power shift firms toward less electricity-intensive and lower-growth activities (Abeberese, 2017). Among micro-firms in Ghana, those without employees lose revenue and profits during outages, while firms with employees adjust hours and wages rather than output (Hardy and McCasland, 2021). At the macroeconomic level, the same unreliability lowers growth (Andersen and Dalgaard, 2013). Beyond these direct effects, electricity constraints also shape firms' long-run investment decisions (Alby et al., 2013). The consistent finding across these settings is that outages impose substantial and unevenly distributed costs, which gives firms a strong private incentive to insure themselves against unreliable supply.

2.2. Self-Generation and the Economics of Backup Power

The standard firm response to an unreliable grid is to self-generate, a response documented throughout the literature. Reinikka and Svensson (2002) show that poor public power induces firms to substitute into private generators, crowding out more productive investment. This finding frame self-generation as costly insurance rather than as a productive choice. Foster and Steinbuks (2009) document that own generation accounts for around 6

percent of the overall installed capacity in Sub-Saharan Africa, roughly 12 percent in low-income and post-conflict economies, and more than 20 percent in countries where the grid is weakest. Steinbuks and Foster (2010) provide the most direct precedent for the present paper, modelling in-house generation across 25 African economies. They find that generator ownership rises with outage exposure, firm size, age, and export orientation. Their evidence suggests that ownership would remain near 20 percent even under a perfectly reliable grid, and that self-generated power costs US$0.30 to 0.70 per kilowatt-hour, which is about three times the price of grid electricity. Oseni and Pollitt (2015) extend this accounting to the outage losses that remain after a firm has installed backup. They show across a large sample of African firms that firms without backup could have cut their outage losses by roughly 6 to 46 percent by self-generating. However, firms that self-generate still bear sizeable unmitigated losses, as a generator rarely covers a firm's entire load. In their study, self-generation is treated synonymous with fossil generation, a view established before the decline in solar costs. Given that solar is cheaper on a levelised-cost basis, outage exposure should drive solar adoption as it drives generator ownership. No firm-level test of this prediction exists for the developing economies.

2.3. Solar, Generators, and the Choice between Self-Generation Technologies

Distributed solar costs have declined substantially, making on-site solar increasingly competitive with diesel self-generation on a levelised-cost basis (IRENA, 2024). The technologies nevertheless differ in their cost structures. Generators require relatively little upfront investment, with fuel accounting for much of its lifetime cost, whereas solar costs are concentrated in the initial investment (Szabó et al., 2011). Evidence from rural off-grid settings

shows that solar home systems can be more expensive per kilowatt-hour than small diesel generators (Baurzhan & Jenkins, 2016). Energy systems studies examine their competition on cost grounds (Yuan et al., 2020), while evidence from hybrid mini grids shows that solar and other renewable sources can complement existing diesel capacity, reduce generation costs while retaining diesel for residual demand and reserve capacity (Blechinger et al., 2016). The technologies also differ in their operational characteristics. Generators are dispatchable, whereas solar without storage depends on sunlight rather than the timing of grid interruptions. Consequently, solar may reduce electricity expenditure without necessarily providing backup when outages occur. Its economic value derives from future electricity-bill savings relative to the initial investment, although households may heavily discount these future returns (De Groote and Verboven, 2019). The duration and frequency of outages may also carry different economic implications. Manufacturing firms in Addis Ababa, for example, are willing to pay approximately twice as much to shorten a typical outage by one hour as to avoid one outage per month (Carlsson et al., 2020).

Solar adoption further depends on firms' ability to meet its substantial upfront cost. Evidence from off-grid solar and rural electrification shows that take-up declines considerably as prices rise (Lee et al., 2020; Burgess et al., 2023), while the socioeconomic gains from electrification depend partly on the quality and productive uses of electricity (Aklin et al., 2017). More broadly, renewable technologies are particularly sensitive to financing conditions, as a larger share of their lifetime costs must be financed upfront (Egli et al., 2018). These constraints are more pronounced in developing economies, where renewable projects face higher costs of capital than in industrialised countries (Steffen, 2020). Firm-level investment also depends on access to

finance (Beck et al., 2005), as well as the capabilities to absorb and operate advanced technologies, which are concentrated among larger, more productive, and internationally connected firms (Verhoogen, 2023). Evidence on generator investment similarly identifies credit access as an important determinant (Steinbuks, 2012). This literature points to two mechanisms underlying firms' self-generation choices. The dispatchability of generators makes their ownership more responsive to outage exposure, particularly outage duration, whereas solar's capital-intensive cost structure makes adoption more dependent on firm capabilities and financing conditions. However, existing evidence largely examines the technologies separately, with limited firm-level comparisons across developing economies. This paper addresses this gap by examining generator and solar adoption within a common empirical framework.

3. A Model of the Self-Generation Choice

This section develops a model of how a firm chooses between self-generation technologies when the grid is unreliable. The model treats self-generation as an investment with two possible sources of value, the outage losses it avoids (Steinbuks and Foster, 2010; Oseni and Pollitt, 2015) and the grid electricity it displaces. Solar in this model differs from the generator in two respects. Without storage, it cannot be dispatched to an outage, and it carries a high upfront cost.

Consider a firm that draws electricity from an unreliable grid. Outages are described by two parameters, the number of outages in a period, n, and the typical duration of an outage in hours, h. Each hour without power costs the firm lost output, an amount that rises with the electricity dependence of

its operations. Let this per-hour loss be denoted by the term in Equation 1, where Q is the value of output the firm would produce in an hour of normal operation and the parameter λ, bounded between zero and one, is the share of that value lost when power is interrupted, a measure of the firm's vulnerability to outages. Vulnerability is high for firms whose operations leave little room for interruption, such as exporters that must meet delivery commitments to foreign buyers.

$$\ell_i = \lambda_i Q_i \tag{1}$$

With no self-generation, the firm's expected loss over the period is the per-hour loss multiplied by the total hours without power, given in Equation 2. Total outage hours are the product of frequency and duration, and in the absence of self-generation the two enter the loss symmetrically.

$$\Lambda^0 = \ell_i n_i h_i \tag{2}$$

The firm can mitigate this loss by installing one or both of two self-generation technologies. The generator carries a fixed cost that is low relative to its capacity, the upfront outlay denoted F_D, and a variable cost per hour of operation, mainly fuel, denoted c_D. The generator is dispatchable, producing exactly when the firm switches it on, and can therefore be matched to the outage. Deploying the generator within a given outage carries a small start-up cost, γ, for switching over, fuelling, and maintaining readiness, incurred once per outage. The generator is worth running in a given event only when the loss it avoids, net of the variable cost, exceeds this start-up cost, which occurs only once the outage is sufficiently long. The annualised net value of owning a generator is given in Equation 3, where r annualises the fixed cost.

$$V_i^D = n_i \max\left\{(\ell_i - c_D)\, h_i - \gamma,\ 0\right\} - rF_D \tag{3}$$

Two conditions are implicit in this specification. The first is that running a generator to displace grid power is never worthwhile, which requires the variable cost to exceed the grid price. This holds empirically, given that self-generation costs several times the grid price. The second is that the generator is worth owning only for firms whose per-hour loss exceeds the variable cost. Equating this payoff and cost yields a threshold duration, given in Equation 4, which distinguishes outages long enough to warrant deployment from those of insufficient duration. Duration is thus the operative margin. A longer typical outage raises the generator's value directly, whereas outages falling below the threshold contribute nothing. The start-up cost γ, incurred once per event, offsets the frequency margin. Consequently, the value of ownership is more elastic with respect to typical duration than to frequency, the model's second prediction. This is not to say that frequency is immaterial. Both longer and more frequent outages raise the generator's value, although duration carries the greater weight.

$$h_i^* = \frac{\gamma}{(\ell_i - c_D)} \tag{4}$$

Solar generation reverses the cost structure and adds a timing problem. Its fixed cost is high, denoted F_S and well above the generators, while its variable cost is near zero. Its output, however, is intermittent, following the sunlight rather than the timing of outages, and without storage it cannot be dispatched to the moment of outage. The value of solar therefore has two parts, given in Equation 5. First, solar provides energy saving from displacing grid electricity at price p over annual solar output G, scaled by a utilisation term θ that rises with the firm's scale and capability. Second, the outage coverage that solar provides incidentally, scaled by s—the probability that solar is generating at the moment the grid fails. Without storage this

probability is bounded well below one and lies outside the firm's control, as solar output cannot be timed to a given event.

$$V_i^S = pG_i\theta_i + s_i\Lambda^0 - rF_S \tag{5}$$

Storage changes the timing problem without changing the cost structure. A battery paired with the panels stores daytime output and releases it at the moment the grid fails, raising the coverage probability to one and making clean self-generation dispatchable in the same sense as the generator. The value of a solar-plus-storage system is given in Equation 6, where the coverage term now enters in full and the variable cost remains near zero. The fixed cost, denoted F_{S+B}, is the sum of the panel cost and the cost of storage capacity. This combined cost exceeds the standalone-solar cost, which in turn stands well above the generators. The generator therefore combines a low fixed cost with a high variable cost, whereas solar combines a high fixed cost with a variable cost near zero, and storage raises the fixed cost further.

$$V_i^{S+B} = pG_i\theta_i + \Lambda^0 - rF_{S+B},\ F_{S+B} = F_S + F_B \tag{6}$$

Two implications follow. First, the coverage term for the hybrid system enters in full, and its value rises with outage exposure in the same direct way as the generator's. The asymmetry the model predicts between the generator, and clean self-generation is therefore not a property of clean generation as such but of dispatchability and capital. Second, the capital hurdle for the hybrid system is the largest of the three technologies, and it binds most tightly in the capital-scarce settings where outages are most severe. A firm that faces long outages and cannot finance the hybrid system directs its available funds to the low-cost dispatchable generator. The clean option that would answer the outage is the one the firm can least afford, which implies

cheaper panels do not displace the generator. In the model, observed solar adoption combines panel-only systems, whose coverage probability stays below one, with storage-backed systems held down by the capital hurdle, and neither responds to outage exposure.

Given that s is bounded below one and cannot be controlled by the firm, outage exposure raises the value of solar only weakly, whereas it raises the value of the dispatchable generator directly. The value of solar depends instead on the displacement saving, which grows with firm scale and capability, and on the firm's ability to finance the large upfront cost. This last point is the capital channel. The firm chooses the self-generation option with the highest payoff among those whose fixed cost it can finance, as summarised in Equation 7, where A denotes the firm's internal funds and credit access. Solar's fixed cost is large while the generator's is small, and the financing constraint therefore binds for solar among firms with limited capital but rarely binds for the generator.

$$U_i^j = V_i^j + \varepsilon_i^j, \quad j_i^* = \underset{j:F_j \leq A_i}{\arg\max}\, U_i^j \tag{7}$$

Equation 7 writes the choice as a random payoff model, the random utility model of discrete choice (McFadden, 1974) applied to a profit-maximising firm. V_i^j is the value of option j from Equations 3, 5 and 6, and ε_i^j collects the parts of the payoff the researcher does not observe, such as management preferences or buyers' requirements. The value of not self-generating is normalised to zero. With ε_i^j following the standard extreme-value distribution, the choice probabilities take the multinomial logit form estimated in Table 4.

Firm capability and vulnerability shape the choice in different ways. A more capable firm uses more of the electricity its panels generate, through θ_i, and can finance more of the fixed cost, through A_i, and solar's value therefore

rises with capability whether or not the firm faces outages (Verhoogen, 2023). A firm whose operations leave little room for interruption faces a high λ_i and values the generator as cover against outages. A firm that is both capable and vulnerable, such as an exporter, gains from both technologies. Without storage, solar covers few outages, and the value of holding both is close to the sum of the two values.

The model yields three predictions about choice probabilities, and each is tested by a different part of the analysis. First, the probability of owning a generator rises with outage exposure, while the probability of adopting solar rises only weakly with exposure. This asymmetry follows from dispatchability and the near-zero outage-coverage probability in Equation 5. Second, the generator response is stronger for outage duration than for frequency, a pattern driven by the threshold in Equation 4, which makes long outages the events worth covering. Third, solar adoption increases with firm capability, such as size, exporting, and digital presence, and with access to capital, and this holds whether or not the firm faces outages. Firms that are both capable and vulnerable to interruption, such as exporters, are more likely to hold both technologies.

4. Data and Empirical Strategy

4.1. The World Bank Enterprise Surveys and the Solar Module

The analysis uses data from the World Bank Enterprise Surveys (WBES; World Bank, 2026a). WBES conducts nationally representative firm-level surveys administered with a standardised questionnaire that covers formal private firms in manufacturing and services. The 2025 and 2026 rounds carry an on-site solar module that asks whether the establishment used on-

site solar panels over the fiscal year, with a follow-up recording the share of the firm's electricity that solar supplied. The module sits alongside the long-standing items on outage frequency, outage duration, and generator ownership. The module captures solar as an on-site self-generation technology, though it does not ask whether solar was installed as outage backup, and the survey records no battery storage. The generator items, by contrast, record a device whose purpose is backup. The analysis therefore compares a technology installed for backup with one installed for self-generation, and the asymmetry documented below partly reflects the distinct functions of the two technologies, as noted in the Introduction. The analysis covers 36 developing economies where the module is available at the time of the analysis, namely 18 in Sub-Saharan Africa, 6 in Latin America and the Caribbean, 5 in East Asia and the Pacific, 3 in South Asia, 2 in the Middle East and North Africa, and 2 in Europe and Central Asia. In addition, 17 high-income economies are used as a benchmark, where solar adoption is recorded. The solar question was unavailable for two countries, India and Poland, which are therefore excluded from the sample. The final estimation sample comprises 11,252 firms, with the high-income economies entering only the analysis of the determinants of solar adoption. Table A.1 reports the per-country pattern of adoption and exposure.

4.2. Self-Generation and Energy Outcomes

The two main adoption outcomes are binary. Generator ownership equals one if the establishment owned or shared a generator over the last fiscal year (WBES question c10), and zero otherwise. The survey does not record fuel type, although most such units are diesel (Lam et al., 2019). Solar adoption equals one if the establishment used on-site solar panels to generate elec-

tricity over the last fiscal year (c43), and zero otherwise. Two continuous outcomes measure the percentage of the establishment's electricity supplied by its generator (c11) and by its solar panels (c44), on a scale of 0 to 100, with non-adopters assigned zero. A three-category self-generation portfolio combines the two indicators and classifies firms as holding a generator only, solar only, or both, which captures the joint adoption decision directly rather than treating one technology as a determinant of the other. Finally, two indicators from the survey's green economy module test whether unreliable electricity induces a broader energy response beyond investment in self-generation capacity. Energy management equals one if the firm reports adopting energy management measures (ge8d), and carbon monitoring equals one if it monitors its own carbon dioxide emissions (ge7). Appendix Table B.1 lists every variable with its survey question and coding.

4.3. Outage Exposure

Outage exposure is measured by two variables that enter every specification together, both from the survey's infrastructure module. Firms first report whether the establishment experienced power outages in the last fiscal year (c6). Those that did report the number of outages in a typical month (c7) and how long a typical outage lasted, in hours and minutes (c8). Outage frequency is the number of outages in a typical month, and outage duration is the typical length of an outage in hours. Firms reporting no outages are assigned zero on both measures, which keeps them in the sample rather than selecting on having outages. The two measures are only modestly correlated, at about 0.23, and capture distinct features of an unreliable grid, the length of a typical interruption and how often interruptions occur. Entering them jointly is central to the paper, given that the model predicts the two mar-

gins matter differently for the generator, a distinction lost when exposure is summarised by a single index.

4.4. Firm Characteristics

All specifications condition on a compact set of firm characteristics that are standard correlates of technology adoption. Firm size is the natural logarithm of the number of permanent full-time employees at the end of the last fiscal year (l1). Firm age is the natural logarithm of one plus the number of years the establishment has been operating (b5). Exporter equals one if direct exports account for more than 0 percent of the establishment's sales (d3c). Foreign ownership equals one if private foreign individuals, companies, or organisations own more than 10 percent of the firm (b2b). Capital city equals one if the establishment is located in the country's capital city (a3b). This baseline control set follows comparable WBES studies of self-generation (Steinbuks and Foster, 2010).

A broader set of capability and finance variables enters the heterogeneity and solar-adoption analyses. Quality certification equals one if the establishment holds an internationally recognised quality certification, such as ISO 9000 (b8). Website equals one if the establishment has its own website (c22b). Manager experience is the natural logarithm of one plus the top manager's years of experience working in the firm's sector (b7). Training equals one if the establishment ran formal training programmes for its permanent full-time employees in the last fiscal year (l10).

The finance measures follow the definitions of the World Bank Enterprise Surveys Indicators Database, which constructs harmonised firm-level indicators under a standard published methodology. A firm is credit constrained if it is fully or partially credit constrained under that methodology.

Fully constrained firms have no external loan and either applied for one and were rejected or did not apply for reasons other than having sufficient capital, such as unfavourable terms or complex procedures. Partially constrained firms have some external finance but were rejected or discouraged when seeking more. Unconstrained firms either did not need a loan or applied and were approved. Bank credit equals one if the establishment has a loan or line of credit from a financial institution. Among firms that purchased fixed assets in the last fiscal year (k4), external investment finance equals one if any part of that purchase was financed from sources other than internal funds. The finance obstacle is the answer to the question "To what degree is access to finance an obstacle to the current operations of this establishment?" (k30), coded 0 for no obstacle, 1 for a minor obstacle, 2 for a moderate obstacle, 3 for a major obstacle, and 4 for a very severe obstacle, and is used for the descriptive comparison in Table A.2. At the country level, credit depth equals one if domestic credit to the private sector as a share of GDP, from the World Development Indicators (World Bank, 2026b) for the most recent available year, lies above the median of the developing-country sample. The court quality index combines the answers to two questions, "To what degree are courts an obstacle to the current operations of this establishment?" (h30), coded 0 for no obstacle to 4 for a very severe obstacle, and agreement with the statement "In resolving commercial disputes, courts are independent and impartial" (j31), coded 1 for strongly disagree to 4 for strongly agree. Each item is standardised, the obstacle item is reversed, and the index is the mean of the items the firm answered, rescaled to mean zero and standard deviation one, with higher values indicating better courts. Country and sector fixed effects absorb remaining institutional and industry-level variation. Responses of "don't know" and refusals, and values outside plausible ranges, are coded

as missing.

4.5. Descriptive Statistics

Table 1 reports summary statistics for the estimation sample. Generators are common, with about 40 percent of firms owning one, whereas on-site solar remains rare at about 11 percent, highlighting the adoption asymmetry examined in the paper. Generators supply about 11 percent of electricity on average, compared with about 4 percent from solar. The typical firm reports outages lasting about two hours and occurring roughly five times per month, with both measures strongly right-skewed. The average establishment employs around 13 workers; about 9 percent export directly and 7 percent have foreign ownership above 10 percent.

Table A.2 reports descriptive differences across self-generation types. Solar-only firms face outage exposure similar to generator-only firms, with typical outages of 3.27 and 2.68 hours respectively, but report lower finance obstacles and higher rates of exporting and website use. Firms holding neither technology report the lowest outage exposure, while exposure is higher among all firms that self-generate. The raw differences therefore offer little evidence that solar and generator adopters differ primarily in outage exposure; instead, they point toward differences in the capability and finance characteristics associated with solar adoption.

4.6. Empirical Strategy

The baseline specification relates each self-generation outcome to the two outage-exposure measures within a fixed-effects framework, given in Equation 8. For firm i in country c and sector s, the outcome y_{ics} is regressed on outage duration and frequency, a vector of firm controls X, and country and

sector fixed effects.

$$y_{ics} = \alpha + \beta_1 \text{ Duration}_{ics} + \beta_2 \text{ Frequency}_{ics} + X_{ics}^{'}\delta + \mu_c + \lambda_s + \varepsilon_{ics} \quad (8)$$

The country effects capture country-level differences across economies, including grid quality, fuel prices, solar irradiance, and renewable-energy policy. The regressions do not add separate controls for public infrastructure. The outage measures are the firm's own experience of the government-provided grid, and controlling for grid quality would absorb the variation under study. National infrastructure provision is common to all firms in an economy and is absorbed by the country effects, and the survey records other infrastructure, such as roads and water, only as perceived obstacles that are likely to respond to the same firm circumstances as the outcomes. The exposure coefficients are identified from variation across firms within the same country and sector. The pooled specifications are estimated with survey weights rescaled such that each economy contributes equally. Binary outcomes are estimated as linear probability models and reproduced as logit average marginal effects in the appendix. The self-generation portfolio is estimated by multinomial logit with the same fixed effects and reported as average marginal effects. These estimators follow from the random payoff model in Section 3. The linear probability and logit models describe the binary choice of holding each technology, and the multinomial logit describes the choice among the self-generation options. Heterogeneity is examined by interacting the two exposure measures with firm and country characteristics. Where a characteristic is constant within an economy, as credit depth is, its level is absorbed by the country effects and only its interactions with exposure are identified. The Gap columns use the difference between the generator and solar indicators as the outcome, which makes each coefficient

equal to the difference between the generator and solar coefficients, with its own standard error. The sample contains 36 country clusters. Inference is based on standard errors clustered by country, with the wild-cluster bootstrap reported alongside as a robustness check that guards against the over-rejection conventional cluster-robust standard errors can produce when the number of clusters is small (Cameron et al., 2008; Roodman et al., 2019).

The estimates are read as conditional associations rather than causal effects, given that the data are a single cross-sectional wave that rules out firm fixed effects. Three sources of endogeneity could bias the exposure coefficients. The first is omitted variables. Local economic development, infrastructure quality, and firm characteristics that the survey does not record could shape both a firm's outage exposure and its self-generation choice. Country and sector fixed effects absorb differences across economies and industries, the firm controls absorb observed differences across firms, and the instrumented specification is also reported with local-development controls. The second is measurement error. Outage frequency and duration are self-reported for a typical month, and classical error in these measures would attenuate the estimates toward zero. The third is reverse causality. A firm that self-generates may notice or report outages differently, which links the outcome to the reported exposure. As a robustness check against all three sources, the paper instruments each firm's exposure with a leave-out mean, the average outage duration and frequency reported by all other firms in its country and locality. This isolates the grid-driven component of exposure, shared across nearby firms, from the firm's own circumstances and reporting. The exclusion restriction is that other firms' outages affect a firm's self-generation choice only through its own exposure, which fails if the shared local grid also proxies for local development. The specification

is therefore reported with and without local-development controls, and the instrument serves as a directional check rather than a preferred estimate.

5. Results

5.1. The Asymmetric Response

The response of self-generation to outage exposure is asymmetric across the two technologies. Table 2 reports the baseline specification with the generator and solar indicators as outcomes. An additional hour of typical outage duration is associated with a 0.0111 increase in the probability of generator ownership, significant at the one percent level. The corresponding estimate for solar adoption is far smaller, at 0.0043, and only marginally significant. The asymmetry is therefore a difference in the strength of the two responses. Table A.3 confirms that the generator and solar duration slopes differ. The duration margin dominates the frequency margin, with the frequency association small and not significant. Among the controls, larger, older, and foreign-owned firms are more likely to run a generator, while larger and exporting firms are more likely to hold solar. Figure 3 shows the same asymmetry at the country level, with generator adoption rising with outage duration across economies and solar adoption rising at roughly half that rate.

5.2. Adoption Margins and Channels

The asymmetry holds for the adoption decision, for the share of electricity each technology supplies, and for broader energy practices. Table 3 extends the baseline across four outcomes, namely the share of electricity from the generator, the share from solar, active energy management, and carbon dioxide monitoring. For the electricity shares, an additional hour

of outage duration is associated with a 0.4776 percentage-point increase in the share of electricity drawn from the generator, significant at the one percent level. In contrast, solar share shows no association with duration and a negative frequency association, significant at the five percent level. Active energy management shows a marginal duration association, significant only at the ten percent level, while carbon monitoring shows no association once sector and country fixed effects are included. The response to unreliability is therefore concentrated in dispatchable fossil capacity rather than spread across energy practices. A consistent secondary pattern reinforces the dispatchability findings. Outage frequency carries a small negative association with solar across the specifications, namely on the solar electricity share (-0.0625), on developing-country solar adoption (-0.0009), and more sharply in Sub-Saharan Africa (-0.0014).

5.3. The Self-Generation Portfolio

Table 4 reports average marginal effects from a multinomial logit for three self-generation categories, namely generator only, solar only, and both. Outage duration is associated with a shift toward generator ownership. An additional hour of outage duration raises the probability of holding a generator only by 0.0111, significant at the one percent level. The effect on solar-only adoption is small (0.0013) and statistically insignificant, while the probability of holding both technologies rises by 0.0023, significant at the one percent level. Exporting separates the categories in a different way. Exporters are 0.0643 less likely to rely on a generator only, significant at the five percent level, and 0.0275 more likely to hold solar only and 0.0290 more likely to hold both technologies, each significant at the one percent level. Table A.2 shows the same pattern in raw shares. Among firms holding both

technologies, 17 percent export, against 12 percent of solar-only firms and 8 percent of generator-only firms. This pattern is consistent with capable firms holding a diversified energy supply, in which the generator provides cover that can be switched on during an outage and solar lowers energy costs while adding incidental cover. Export buyers' environmental requirements may also play a role, which the survey does not allow the paper to test. Figure 1 shows a similar pattern, with self-generation increasing with outage exposure, predominantly through generator ownership.

5.4. Credit, Courts, and the Generator Margin

Table 5 interacts outage exposure with the firm's own financing constraint and, separately, with the depth of its country's credit market. Credit depth enters the firm's choice through the financing condition in Equation 7, given that the funds a firm can draw on for the fixed cost depend on the supply of loans, asset finance, and leasing in its economy. Most interaction terms are statistically insignificant. Notably, the significant interactions are concentrated on outage frequency. In the generator equation, the response to frequency is stronger in countries with deeper credit markets, with an interaction coefficient of 0.0097, significant at the five percent level. The difference between the generator and solar frequency responses is also larger, at 0.0094, while the firm's own financing constraint produces no comparable gap. The only significant own-constraint interaction is a small negative frequency effect on solar adoption (-0.0019), with no corresponding effect on generator ownership. The generator-solar duration gap is also larger in deeper credit markets, at 0.0081, although the underlying duration interactions are not statistically significant. These results are consistent with the fixed-cost nature of generator investment. Deeper credit markets may enable firms facing

frequent interruptions to respond through generator ownership, whereas the duration margin shows no comparable credit interaction. Among financially constrained firms, the weak solar response does not strengthen, and generator adoption is not more responsive to outage duration. The results therefore provide no evidence that greater access to credit shifts outage-exposed firms toward solar. Table A.10 turns to the legal side of the capital channel, using the firm's own court quality index. The index is not associated with generator ownership or solar adoption, with coefficients of 0.0005 and 0.0025, and none of its interactions with outage duration or frequency is statistically significant. The generator response to outage duration remains 0.0108 per hour, significant at the one percent level, while the solar response remains insignificant. Firms' assessment of the courts therefore does not change how either technology responds to outages.

5.5. Capability, Capital, and Solar Adoption

Outage exposure explains generator ownership but not solar adoption in developing economies, as Sections 5.1 to 5.3 show. This section asks what does explain solar adoption, turning to firm capability and capital. Table 6 relates solar adoption to firm capability measures while controlling for outage exposure, allowing the two relationships to be examined jointly across three samples, namely the high-income benchmark, the full developing-country sample, and Sub-Saharan Africa. In the developing-country sample, outage exposure is not statistically associated with solar adoption, whereas adoption increases with firm size, exporting, and website use, with marginal effects of 0.0319, 0.0629, and 0.0432, respectively, all significant at the one percent level. Figure 4 illustrates the size asymmetry, with solar adopters having a substantially higher employment distribution than non-adopters. Figure 5

shows solar adoption by firm size, comparing developing economies with the high-income comparison group. Solar adoption rises from 10.3 percent among small firms to 14.8 percent among large firms in developing economies and from 8.2 to 25.6 percent in the high-income comparison group. Access to formal credit, measured by whether the firm holds a bank loan or line of credit, is not individually significant in any sample. The finance relationship therefore appears to operate through broader firm capability rather than through credit access. Table A.2 provides complementary descriptive evidence. Firms adopting both technologies are the largest and most capable, while solar-only firms, despite being smaller than generator-only firms, report the lowest finance obstacle and credit constraint and a higher export rate. Their outage exposure is nevertheless similar to that of generator-only firms. Together with the exporter results in Table 4, this pattern fits solar as a capital investment made by capable firms, which combine it with a generator when they need cover against outages. This pattern matches the model. Exporters, whose operations leave little room for interruption, are more likely to hold both technologies, and solar adoption rises with size, exporting, and website use whether or not the firm faces outages. The insignificant coefficient on bank credit once capability is controlled for is consistent with capable firms financing more of the fixed cost from internal funds.

Figure 2 provides corresponding cross-country evidence. Solar adoption shows no systematic relationship with outage incidence. Adoption rates are 27.6–35.5 percent in the Netherlands, Austria, and Germany, despite low outage incidence, compared with 0.6–1.4 percent in Ethiopia, Guinea, and Mozambique, where 58–91 percent of firms report outages (Table A.1). This pattern is inconsistent with outage exposure being the primary driver of solar adoption. The high-income benchmark provides a useful comparison as

outages are rare and short, with typical firms reporting 0.0–0.8 outages per month, leaving limited scope for a necessity channel. In these economies, firm size and managerial experience are the capability measures significantly associated with solar adoption, while exporting and certification are positively associated but not significant. Managerial experience is negative and insignificant in developing economies but positive and significant in the high-income sample, while foreign ownership is negative in the latter and close to zero in the former. The evidence therefore does not imply a uniform set of determinants across settings. Nevertheless, firm capability, most consistently firm size, is positively associated with solar adoption in both high-outage and reliable-grid environments.

Table 7 examines the capital mechanism more directly through firms' investment and financing decisions. In the first two columns, a firm that purchased fixed assets in the previous year is 0.0785 more likely to own a generator, significant at the one percent level, but the association with solar adoption is not significant. Given that a generator is itself a fixed asset, the generator association is partly mechanical; the absence of a corresponding relationship for solar, which is also a fixed asset, is the informative part of the comparison. Firms undertaking lumpy capital expenditure appear to direct it toward dispatchable generation rather than intermittent solar, consistent with the dispatchability mechanism. The final two columns examine the financing of investment among firms that invested. Reliance on external investment finance rather than internal funds is associated with 0.0275 higher solar adoption in developing economies, with no corresponding association in the high-income benchmark. The developing-country estimate is only marginally significant. The comparison across the two samples is therefore more informative than either coefficient, suggesting that external finance is

more relevant to solar adoption where capital is relatively constrained.

5.6. Robustness

The asymmetry is robust across the specifications reported in the appendix. Table A.3 reports the difference between the generator and solar duration coefficients from the baseline specification without interactions. The difference is 0.0068 and rejects equality of the generator and solar duration slopes at the five percent level. The 95 percent confidence interval for the solar duration coefficient, from -0.0009 to 0.0095, remains below the generator point estimate of 0.0111. Table A.4 shows that the pattern holds across firm-size classes, while Table A.5 shows similar results across regions. The interaction terms are jointly insignificant in both specifications. Some individual interactions are significant with clustered standard errors, but none is jointly significant. A direct test of slope equality, reported as the difference between the generator and solar duration coefficients in the Gap columns, rejects equality at the five percent level in the regional specification but not in the firm-size specification. Table A.6 considers alternative measures of outage exposure. Outage duration, the frequency–duration interaction, and an indicator for experiencing any outage are each positively and significantly associated with generator ownership, with no significant association with solar adoption. Outage frequency is positive but not significant. Firms experiencing any outage are 0.1388 more likely to own a generator, with no corresponding increase in solar adoption. Table A.7 reproduces the binary outcomes using logit average marginal effects and yields the same asymmetry. Table A.8 excludes influential countries sequentially, including the country with the highest solar adoption and the three largest samples. The generator–duration association remains between 0.0111 and

0.0120 per additional hour, while the solar association remains small and, at most, marginally significant.

Table A.9 examines reverse causality and measurement error in self-reported outages using the average exposure reported by other firms in the same country and locality as instruments. The frequency instrument is strong, with a first-stage F-statistic of 126.9, whereas the duration instrument is weak, with a first-stage F-statistic of 4.9 and a joint Kleibergen–Paap rk F-statistic of 3.4. The IV estimates are therefore interpreted as a directional check rather than as preferred magnitudes. The instrumented duration coefficient for generator ownership remains positive and significant at the five percent level after controlling for local development, while the solar coefficient remains insignificant. The Durbin–Wu–Hausman test does not reject exogeneity for either outcome, providing no evidence of systematic endogeneity in the reported outage measures. Overall, the appendix results consistently show a stronger relationship between outage exposure and generator ownership than between outage exposure and solar adoption.

6. Conclusions

This paper uses the 2025 and 2026 rounds of the World Bank Enterprise Surveys to study how firms in 36 developing economies choose between the generator and solar self-generation when the grid is unreliable, with 17 high-income economies held out as a benchmark. The analysis separates two mechanisms. The first is dispatchability. A generator can be switched on at the moment of an outage and solar without storage is intermittent, which implies that outage exposure should track generator adoption and not solar adoption. The evidence supports this hypothesis. Generator ownership is

associated with the duration of outages, while their frequency shows no significant association. The association with solar adoption is weak, marginally significant at the ten percent level. Firms exposed to worse outages are more likely to hold both a generator and solar than to hold only solar. The second mechanism is capital. Solar requires a large outlay before it produces any power, which implies that its adoption should track capability and finance. The evidence in the analysis supports this. Solar adopters are larger, more likely to export, and more likely to have a website, with firm size, the clearest capability measure, associated with solar adoption in the high-income benchmark, where outages are rare. A third result follows from combining the two mechanisms. Deeper credit does not move outage-exposed firms toward solar, consistent with the binding constraint being the capital needed to make solar dispatchable rather than the price of panels.

The two results have different interpretations. The outage-response asymmetry is consistent with the importance of dispatchability but does not identify relative costs. Solar need not respond to outages even if its lifetime cost is low. The relationship between solar adoption and firm capability instead points to the role of upfront capital in determining adoption. Overall, the results describe two different forms of self-generation. Generators provide an immediate response to power interruptions, with costs incurred largely through fuel use. Solar represents a longer-term investment that requires sufficient capital to finance the initial outlay. The evidence therefore suggests that firms adopt the two technologies for different purposes. The generator serves as cover against outages, while solar is a capital investment that lowers energy costs and provides incidental cover, and capable firms, exporters in particular, combine the two.

Several limitations qualify these conclusions. The data are cross-sectional

and do not permit firm fixed effects or analysis of adoption over time. The estimates therefore represent conditional associations. The leave-out-mean instrument serves as a robustness check on omitted local conditions, measurement error, and reverse causality, but it does not establish causal effects. The solar measure records on-site solar self-generation rather than solar used specifically as backup, and the survey does not record battery storage. The role of dispatchability is therefore inferred from the characteristics of the technologies rather than directly observed. The sample also covers formal firms above a minimum size threshold and may under-represent the smallest and most financially constrained firms. The high-income sample is used as a benchmark and is not intended to represent developed economies. The generator and solar questions also differ in their framing, with the former referring to backup and the latter to annual self-generation. Future survey waves could provide a more direct test by recording battery capacity, grid connection, and the ability of solar systems to operate independently of the grid.

The policy implications concern the two constraints separately. Solar adoption may respond to financing arrangements that reduce or spread the upfront investment, including asset-based finance, leasing, pay-as-you-go arrangements, and partial credit guarantees. The results indicate that financing conditions remain relevant even as the cost of solar technology has fallen. At the same time, solar without storage cannot provide the same service as a generator during an outage. Large solar adoption therefore need not reduce generator use among firms with severe reliability problems. A cleaner substitute requires both solar generation and storage, with financing that addresses the upfront cost of the combined system. Table 7 supports this interpretation. External investment finance is positively associated with so-

lar adoption among investing firms in developing economies, but not in the high-income benchmark. The results therefore point to financing for clean, dispatchable self-generation as a relevant margin for reducing firms' reliance on generators while maintaining reliable electricity supply.

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Tables

Table 1: Summary Statistics

	Mean	SD	Min	Max	N
Panel A. Energy outcomes					
Has generator (=1)	0.400	0.490	0.00	1.00	11,252
Has solar (=1)	0.109	0.312	0.00	1.00	11,252
Generator % of electricity	10.722	21.417	0.00	100.00	11,252
Solar % of electricity	3.913	14.626	0.00	100.00	11,252
Energy management (=1)	0.318	0.466	0.00	1.00	11,252
CO_2 monitoring (=1)	0.134	0.340	0.00	1.00	11,252
Panel B. Self-generation portfolio					
Generator only (=1)	0.344	0.475	0.00	1.00	11,252
Solar only (=1)	0.053	0.225	0.00	1.00	11,252
Generator and solar (=1)	0.056	0.230	0.00	1.00	11,252
Panel C. Outage exposure					
Outages per month	5.211	11.200	0.00	200.00	11,252
Outage duration (hrs)	2.031	3.575	0.00	72.00	11,252
Outages per month, other firms in cell	5.249	7.142	0.00	41.70	11,243
Outage duration (hrs), other firms in cell	2.083	1.826	0.00	11.30	11,243
Panel D. Firm characteristics					
Employees (ln)	2.584	1.023	0.00	9.80	11,252
Firm age (ln)	2.629	0.746	0.00	5.02	11,252
Exporter (=1)	0.085	0.279	0.00	1.00	11,252
Foreign-owned (>10%)	0.071	0.256	0.00	1.00	11,252
In capital city (=1)	0.506	0.500	0.00	1.00	11,252
Panel E. Capability					
Quality certification (=1)	0.079	0.269	0.00	1.00	11,252
Has website (=1)	0.541	0.498	0.00	1.00	11,252
Manager experience (ln)	2.764	0.684	0.69	4.26	11,252
Offers training (=1)	0.297	0.457	0.00	1.00	11,243
Panel F. Investment and finance					
Invested in fixed assets (=1)	0.378	0.485	0.00	1.00	11,237
Investment externally financed (=1)	0.513	0.500	0.00	1.00	3,936
Credit constrained (=1)	0.406	0.491	0.00	1.00	11,252
Has bank loan/credit line (=1)	0.303	0.460	0.00	1.00	11,252
Finance obstacle (0–4)	1.661	1.424	0.00	4.00	11,252
Credit-deep country (=1)	0.514	0.500	0.00	1.00	11,129
Courts an obstacle to operations (0–4)	0.892	1.140	0.00	4.00	10,796
Courts independent and impartial (1–4)	2.800	0.969	1.00	4.00	10,614
Court quality index (SD)	−0.079	1.045	−3.51	1.50	11,130

Table 2: Outage Exposure and Self-Generation Adoption

	Generator		**Solar**	
	(1)	**(2)**	**(3)**	**(4)**
Outage duration (hrs)	0.0111***	0.0111***	0.0042	0.0043*
	(0.0026)	(0.0026)	(0.0025)	(0.0025)
Outages per month	0.0011	0.0011	−0.0009	−0.0009
	(0.0022)	(0.0022)	(0.0006)	(0.0006)
Employees (ln)	0.1155***	0.1150***	0.0371***	0.0392***
	(0.0113)	(0.0114)	(0.0065)	(0.0065)
Firm age (ln)	0.0378***	0.0378***	−0.0069	−0.0067
	(0.0119)	(0.0118)	(0.0059)	(0.0059)
Exporter (=1)	−0.0349	−0.0362	0.0685***	0.0741***
	(0.0336)	(0.0337)	(0.0231)	(0.0237)
Foreign-owned (>10%)	0.0919***	0.0923***	0.0216	0.0196
	(0.0248)	(0.0250)	(0.0209)	(0.0212)
In capital city (=1)	0.0009	0.0014	0.0027	0.0000
	(0.0301)	(0.0301)	(0.0293)	(0.0291)
Constant	−0.0308	−0.0233	0.0191	−0.0174
	(0.0417)	(0.0520)	(0.0246)	(0.0335)
Observations	11,252	11,252	11,252	11,252
Country FE	Yes	Yes	Yes	Yes
Sector FE	No	Yes	No	Yes
Wild-cluster p (duration)		0.0005		0.0989
Wild-cluster p (frequency)		0.7367		0.2970
Adjusted R^2	0.2822	0.2822	0.1698	0.1719

Notes: Linear probability model; SE clustered by country. * p<0.10, ** p<0.05, *** p<0.01.

Table 3: Outage Exposure, Electricity Shares, and Green Practices

	Electricity share (%)		**Green coping**	
	Generator	**Solar**	**Energy management**	**CO2 monitoring**
	(1)	**(2)**	**(3)**	**(4)**
Outage duration (hrs)	0.4776***	0.2462	0.0063*	−0.0017
	(0.1330)	(0.1893)	(0.0037)	(0.0026)
Outages per month	0.0158	−0.0625**	−0.0008	−0.0001
	(0.0995)	(0.0302)	(0.0013)	(0.0006)
Employees (ln)	2.8806***	0.5949**	0.0680***	0.0436***
	(0.5000)	(0.2668)	(0.0109)	(0.0103)
Firm age (ln)	0.0246	−0.3794	−0.0037	0.0027
	(0.5158)	(0.3386)	(0.0091)	(0.0070)
Exporter (=1)	−1.3142	3.7238***	0.0439	0.1171***
	(0.8696)	(1.3422)	(0.0423)	(0.0279)
Foreign-owned (>10%)	2.9244	0.0456	0.0733*	0.1059***
	(1.8258)	(0.6531)	(0.0373)	(0.0289)
In capital city (=1)	−1.1845	−0.0629	−0.0116	0.0151
	(1.5164)	(1.3110)	(0.0244)	(0.0133)
Constant	5.1714**	1.3595	0.1937***	0.0486
	(2.0974)	(1.6611)	(0.0455)	(0.0368)
Observations	11,252	11,252	11,252	11,252
Country FE	Yes	Yes	Yes	Yes
Sector FE	Yes	Yes	Yes	Yes
Wild-cluster p (duration)	0.0023	0.2911	0.1151	0.5465
Wild-cluster p (frequency)	0.9496	0.1483	0.7883	0.8901
Adjusted R^2	0.2856	0.1343	0.1324	0.1387

Notes: Cols (1)–(2) are OLS on the electricity share, the rest linear probability models; SE clustered by country. * p<0.10, ** p<0.05, *** p<0.01.

Table 4: Outage Exposure and the Self-Generation Portfolio (Average marginal effect)

	Generator only **(1)**	**Solar only** **(2)**	**Both** **(3)**
Outage duration (hrs)	0.0111***	0.0013	0.0023***
	(0.0031)	(0.0011)	(0.0007)
Outages per month	0.0011	−0.0002	−0.0003
	(0.0013)	(0.0003)	(0.0006)
Employees (ln)	0.0811***	0.0054	0.0293***
	(0.0094)	(0.0044)	(0.0033)
Firm age (ln)	0.0392***	−0.0038	−0.0017
	(0.0132)	(0.0039)	(0.0054)
Exporter (=1)	−0.0643**	0.0275***	0.0290***
	(0.0314)	(0.0089)	(0.0099)
Foreign-owned (>10%)	0.0713***	0.0075	0.0153
	(0.0203)	(0.0128)	(0.0147)
In capital city (=1)	−0.0019	−0.0012	0.0013
	(0.0268)	(0.0127)	(0.0185)
Observations	11,252	11,252	11,252
Country FE	Yes	Yes	Yes
Sector FE	Yes	Yes	Yes

Notes: Multinomial-logit average marginal effects; SE clustered by country. * p<0.10, ** p<0.05, *** p<0.01.

Table 5: Outage Response by Firm and Country Credit Access

	Firm credit-constrained			Country credit-deep		
	Generator	Solar	Gap	Generator	Solar	Gap
	(1)	(2)	(3)	(4)	(5)	(6)
Outage duration (hrs)	0.0118***	0.0053*	0.0065	0.0103***	0.0022	0.0081**
	(0.0033)	(0.0031)	(0.0041)	(0.0029)	(0.0028)	(0.0031)
Outages per month	0.0018	−0.0001	0.0019	0.0003	−0.0009	0.0012
	(0.0025)	(0.0004)	(0.0023)	(0.0022)	(0.0007)	(0.0019)
Employees (ln)	0.1143***	0.0392***	0.0751***	0.1149***	0.0398***	0.0751***
	(0.0115)	(0.0066)	(0.0121)	(0.0114)	(0.0065)	(0.0120)
Firm age (ln)	0.0376***	−0.0065	0.0441***	0.0319***	−0.0068	0.0387***
	(0.0117)	(0.0059)	(0.0141)	(0.0106)	(0.0061)	(0.0135)
Exporter (=1)	−0.0364	0.0742***	−0.1106***	−0.0291	0.0701***	−0.0992**
	(0.0337)	(0.0235)	(0.0381)	(0.0339)	(0.0240)	(0.0377)
Foreign-owned (>10%)	0.0895***	0.0176	0.0719**	0.0889***	0.0194	0.0696**
	(0.0247)	(0.0207)	(0.0304)	(0.0250)	(0.0211)	(0.0301)
In capital city (=1)	0.0005	−0.0003	0.0008	0.0031	0.0007	0.0024
	(0.0298)	(0.0290)	(0.0276)	(0.0300)	(0.0291)	(0.0277)
Credit constrained	−0.0002	0.0153	−0.0155			
	(0.0222)	(0.0155)	(0.0284)			
Outage duration (hrs) × Credit constrained	−0.0015	−0.0021	0.0005			
	(0.0037)	(0.0030)	(0.0047)			
Outages per month × Credit constrained	−0.0016	−0.0019***	0.0003			
	(0.0012)	(0.0006)	(0.0015)			
Outage duration (hrs) × Credit-deep country				0.0002	0.0047	−0.0045
				(0.0069)	(0.0046)	(0.0074)
Outages per month × Credit-deep country				0.0097**	0.0003	0.0094**
				(0.0039)	(0.0011)	(0.0041)
Constant	−0.0198	−0.0236	0.0038	−0.0109	−0.0255	0.0146
	(0.0550)	(0.0364)	(0.0620)	(0.0507)	(0.0335)	(0.0600)
Observations	11,252	11,252	11,252	11,129	11,129	11,129
Country FE	Yes	Yes	Yes	Yes	Yes	Yes
Sector FE	Yes	Yes	Yes	Yes	Yes	Yes
Adjusted R^2	0.2825	0.1732	0.1991	0.2834	0.1575	0.1849
Wild-cluster p (duration int.)	0.6741	0.5056	0.9169	0.9771	0.3657	0.5584
Wild-cluster p (freq int.)	0.0956	0.1547	0.8282	0.0290	0.8102	0.0258
Wild-cluster p (gap slope, duration)			0.1119			0.0318
Wild-cluster p (gap slope, frequency)			0.5344			0.5855

*Notes: Outage exposure interacted with the firm credit constraint (cols 1–3) and above-median country credit depth (cols 4–6); credit constrained = fully or partially credit constrained; credit-deep = domestic credit to the private sector (percent of GDP) above the developing-sample median; Gap = generator-solar, SE clustered by country. * p<0.10, ** p<0.05, *** p<0.01.*

Table 6: Firm Capability and Solar Adoption

	Solar adoption (=1)		
	Advanced	Developing	SSA
	(1)	(2)	(3)
Outage duration (hrs)		0.0041	0.0026
		(0.0025)	(0.0026)
Outages per month		−0.0009*	−0.0014***
		(0.0005)	(0.0004)
Employees (ln)	0.0442***	0.0319***	0.0248***
	(0.0113)	(0.0064)	(0.0069)
Exporter (=1)	0.0063	0.0629***	0.0931**
	(0.0219)	(0.0218)	(0.0406)
Quality certification (=1)	0.0338	0.0287	0.0004
	(0.0269)	(0.0244)	(0.0464)
Has website (=1)	−0.0042	0.0432***	0.0545**
	(0.0087)	(0.0137)	(0.0192)
Manager experience (ln)	0.0247**	−0.0096	−0.0060
	(0.0094)	(0.0081)	(0.0148)
Foreign-owned (>10%)	−0.0384*	0.0105	0.0007
	(0.0212)	(0.0209)	(0.0277)
Has bank loan/credit line (=1)	0.0193	0.0214	0.0290
	(0.0145)	(0.0151)	(0.0313)
Constant	−0.0220	−0.0193	0.0133
	(0.0496)	(0.0296)	(0.0443)
Observations	9,360	11,252	6,135
Country FE	Yes	Yes	Yes
Sector FE	Yes	Yes	Yes
Adjusted R^2	0.1794	0.1775	0.1433
Wild-cluster p (duration)		0.1052	0.3671
Wild-cluster p (frequency)		0.2578	0.0950

Notes: Solar adoption on firm-capability covariates; col 1 is the 17 high-income economies, cols 2–3 developing and Sub-Saharan Africa, SE clustered by country. * p<0.10, ** p<0.05, *** p<0.01.

Table 7: Capital Deployment and the Self-Generation Choice

	Capital deployment		External finance → solar	
	Generator (1)	Solar (2)	Developing (3)	Advanced (4)
Outage duration (hrs)	0.0104***	0.0041	0.0016	
	(0.0026)	(0.0024)	(0.0027)	
Outages per month	0.0010	−0.0010	−0.0001	
	(0.0022)	(0.0006)	(0.0007)	
Employees (ln)	0.1101***	0.0376***	0.0397***	0.0559***
	(0.0113)	(0.0067)	(0.0080)	(0.0159)
Firm age (ln)	0.0377***	−0.0065	−0.0028	0.0338**
	(0.0115)	(0.0059)	(0.0107)	(0.0137)
Exporter (=1)	−0.0418	0.0733***	0.0792***	0.0095
	(0.0323)	(0.0230)	(0.0257)	(0.0326)
Foreign-owned (>10%)	0.0896***	0.0192	0.0323	−0.0768**
	(0.0243)	(0.0212)	(0.0312)	(0.0303)
In capital city (=1)	−0.0028	−0.0004	−0.0385	−0.0664***
	(0.0300)	(0.0284)	(0.0243)	(0.0220)
Invested in fixed assets (=1)	0.0785***	0.0203		
	(0.0164)	(0.0169)		
Investment externally financed (=1)			0.0275*	−0.0030
			(0.0146)	(0.0175)
Constant	−0.0387	−0.0210	−0.0203	0.0056
	(0.0508)	(0.0342)	(0.0435)	(0.0616)
Observations	11,237	11,237	3,936	5,062
Country FE	Yes	Yes	Yes	Yes
Sector FE	Yes	Yes	Yes	Yes
Wild-cluster p (capital measure)	0.0001	0.2621	0.0759	0.8664
Adjusted R^2	0.2870	0.1730	0.2255	0.1812

Notes: Cols 1–2 the full developing sample, cols 3–4 investors only; SE clustered by country. * p<0.10, ** p<0.05, *** p<0.01.

Appendix A. Additional tables

Table A.1: Per-Country Adoption and Outage Exposure

Country	N	Solar %	Solar % of electricity	Generator %	Generator % of electricity	Outage incidence %	Outages per month	Loss % sales
Panel A. Developing economies								
Sub-Saharan Africa								
Burundi	151	7.7	14.8	31.8	37.5	93.4	5.5	1.9
Comoros	130	16.6	55.2	55.5	48.4	91.2	42.3	7.2
Ethiopia	867	1.4	14.9	55.3	14.4	86.7	6.6	3.3
Gabon	68	3.8	18.5	60.2	27.7	76.8	6.8	3.6
Guinea	159	0.6	19.0	50.5	18.1	91.0	3.1	0.1
Guinea Bissau	133	10.0	43.8	44.3	34.3	70.9	2.6	0.6
Kenya	992	9.4	21.2	60.4	14.5	74.8	2.8	2.7
Liberia	145	2.1	15.6	89.6	52.2	68.5	6.2	0.8
Malawi	132	11.2	12.8	35.3	13.7	88.3	8.7	1.3
Mauritania	146	10.3	23.8	46.0	19.6	82.5	4.3	1.0
Mozambique	582	1.0	35.3	20.5	17.0	58.0	2.7	2.2
Niger	127	8.6	36.9	72.4	21.8	76.3	7.0	1.9
Nigeria	872	22.7	39.7	84.9	51.3	81.3	10.8	5.4
Sao Tome And Principe	108	7.9	37.2	49.4	24.4	71.1	6.3	2.3
Somalia	217	8.9	26.3	12.3	12.3	48.5	1.5	1.3
Uganda	521	11.7	24.7	38.6	11.1	79.1	3.8	3.7
Zambia	463	31.3	37.6	55.8	48.7	88.6	21.3	5.1
Zimbabwe	322	45.5	39.0	53.9	26.8	53.6	3.9	1.9
Sub-Saharan Africa (pooled)	6135	11.7	34.2	50.9	30.5	76.7	8.1	2.4
East Asia & Pacific								
Fiji	92	6.5	11.6	36.2	26.4	82.7	2.0	1.2
Kiribati	123	42.6	30.4	20.3	20.6	89.1	3.6	1.1
Mongolia	498	4.3	42.3	16.8	21.3	15.5	0.3	0.4
Solomon Islands	82	4.5	15.9	69.1	21.6	78.5	3.0	3.7
Thailand	565	4.3	47.1	0.9	62.3	6.8	0.1	0.1
East Asia & Pacific (pooled)	1360	12.4	29.3	28.6	22.9	54.5	1.8	1.2
South Asia								
Afghanistan	391	49.6	47.8	65.5	36.6	41.3	13.2	1.6
Maldives	93	5.9	28.7	13.4	49.7	58.8	1.1	1.3
Sri Lanka	436	8.8	62.3	17.9	31.7	29.7	0.9	0.2
South Asia (pooled)	920	21.4	48.0	32.3	37.5	43.3	5.1	1.0
Middle East & North Africa								
Djibouti	140	3.5	22.0	64.8	18.1	55.5	1.9	0.1
Egypt	938	0.0	16.1	5.2	12.0	35.2	4.2	1.1
Middle East & North Africa (pooled)	1078	1.7	22.0	35.0	17.7	45.3	3.0	0.6
Latin America & Caribbean								
Argentina	412	4.8	15.0	15.7	3.7	25.5	0.8	0.1
Belize	122	9.3	36.8	51.1	17.3	76.9	1.9	1.5
Bolivia	431	1.8	13.2	4.4	32.8	19.0	0.4	0.5
Guatemala	119	10.8	39.1	26.5	12.2	67.0	2.1	0.3
St Lucia	96	10.1	23.3	31.3	4.1	27.3	0.5	0.2
Suriname	131	4.2	25.3	23.7	21.3	57.8	1.3	1.9
Latin America & Caribbean (pooled)	1311	6.8	29.3	25.5	13.4	45.6	1.2	0.7
Europe & Central Asia								
Albania	298	8.6	65.9	19.0	4.1	23.9	1.0	0.3
Kosovo	150	3.2	39.1	40.7	10.1	43.9	2.9	0.3
Europe & Central Asia (pooled)	448	5.9	58.6	29.9	8.2	33.9	1.9	0.3

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Table A.1: *continued*

Country	N	Solar %	Solar % of electricity	Generator %	Generator % of electricity	Outage incidence %	Outages per month	Loss % sales
Developing economies (pooled)	11252	10.9	35.8	40.0	26.8	61.5	5.2	1.6
Panel B. High-income benchmark								
Australia	155	28.6	27.5	22.9	2.5	18.2	0.3	0.0
Brunei Darussalam	73	6.6	8.5	11.3	16.0	9.5	0.1	0.0
Japan	1512	6.0	10.0	10.3	1.7	1.0	0.0	0.0
Kuwait	140	0.0	.	0.2	35.9	0.0	0.0	0.0
Oman	171	0.3	16.3	7.4	45.8	18.4	0.3	0.1
Qatar	475	0.0	.	11.4	17.3	0.0	0.0	0.0
Saudi Arabia	980	0.1	22.9	1.9	31.5	0.0	0.0	0.0
Chile	694	8.3	31.8	34.8	13.7	36.3	0.8	0.2
Austria	550	33.1	35.5	4.9	13.9	5.8	0.2	0.0
Denmark	489	10.2	29.2	12.3	8.4	3.5	0.0	0.0
Finland	348	7.4	17.3	7.8	1.4	7.4	0.1	0.0
France	726	6.2	26.9	10.4	2.5	13.0	0.3	0.1
Germany	1715	27.6	35.0	4.8	8.8	3.5	0.1	0.0
Lithuania	195	3.9	60.8	6.8	3.0	8.2	0.1	0.0
Netherlands	524	35.5	44.7	9.8	8.3	8.5	0.2	0.1
Norway	234	2.3	10.9	9.6	5.0	7.3	0.1	0.0
Switzerland	379	17.5	35.4	6.3	3.9	2.1	0.0	0.0
High-income benchmark (pooled)	9360	11.4	32.9	10.2	10.2	8.4	0.2	0.0

Notes: Solar % of electricity and Generator % of electricity give the electricity share from each technology among the firms that use it, and are therefore conditional on adoption. Panel B economies are excluded from the estimation sample and serve as the comparison group in Table 6 and Figure 5.

Table A.2: Firm Characteristics by Self-Generation Type

	Neither	**Generator only**	**Solar only**	**Both**
Outage duration (hrs)	1.39	2.68	3.27	3.19
Outages per month	3.57	7.06	7.41	7.79
Employees (ln)	2.36	2.85	2.52	3.27
Exporter (=1)	0.08	0.08	0.12	0.17
Finance obstacle (0–4)	1.70	1.66	1.43	1.57
Credit constrained (=1)	0.42	0.39	0.36	0.41
Has bank loan/credit line (=1)	0.28	0.33	0.28	0.37
Has website (=1)	0.51	0.56	0.57	0.66

Notes: Estimation-sample firms split by which backup technology the firm uses.

Table A.3: The Generator-Solar Slope Difference and the Bound on the Solar Response

	Generator (1)	**Solar** (2)	**Gap** (3)
Outage duration (hrs)	0.0111***	0.0043*	0.0068**
	(0.0026)	(0.0025)	(0.0028)
Outages per month	0.0011	−0.0009	0.0020
	(0.0022)	(0.0006)	(0.0020)
Employees (ln)	0.1150***	0.0392***	0.0757***
	(0.0114)	(0.0065)	(0.0120)
Firm age (ln)	0.0378***	−0.0067	0.0445***
	(0.0118)	(0.0059)	(0.0142)
Exporter (=1)	−0.0362	0.0741***	−0.1103***
	(0.0337)	(0.0237)	(0.0380)
Foreign-owned (>10%)	0.0923***	0.0196	0.0727**
	(0.0250)	(0.0212)	(0.0300)
In capital city (=1)	0.0014	0.0000	0.0014
	(0.0301)	(0.0291)	(0.0278)
Constant	−0.0233	−0.0174	−0.0059
	(0.0520)	(0.0335)	(0.0608)
Observations	11,252	11,252	11,252
Country FE	Yes	Yes	Yes
Sector FE	Yes	Yes	Yes
Adjusted R^2	0.2822	0.1719	0.1992
Solar duration 95pct CI lower		−0.0009	
Solar duration 95pct CI upper		0.0095	
Wild-cluster p (gap slope, duration)			0.0283
Wild-cluster p (gap slope, frequency)			0.3975

*Notes: Baseline (Table 2) spec for the generator, solar, and the generator-solar gap; the Gap column tests slope equality and the Solar column reports the 95% CI on the duration coefficient, SE clustered by country. * p<0.10, ** p<0.05, *** p<0.01.*

Table A.4: Firm-Size Heterogeneity

	Generator (1)	**Solar** (2)	**Gap** (3)
Outage duration (hrs)	0.0097***	0.0057*	0.0040
	(0.0026)	(0.0031)	(0.0030)
Outages per month	0.0007	−0.0007	0.0015
	(0.0024)	(0.0007)	(0.0020)
Employees (ln)	0.1171***	0.0394***	0.0777***
	(0.0130)	(0.0063)	(0.0141)
Firm age (ln)	0.0374***	−0.0067	0.0441***
	(0.0119)	(0.0060)	(0.0145)
Exporter (=1)	−0.0333	0.0725***	−0.1058***
	(0.0338)	(0.0233)	(0.0378)
Foreign-owned (>10%)	0.0932***	0.0197	0.0734**
	(0.0257)	(0.0215)	(0.0310)
In capital city (=1)	0.0029	−0.0001	0.0031
	(0.0305)	(0.0291)	(0.0279)
Medium firm (20–99)	0.0031	0.0101	−0.0070
	(0.0238)	(0.0135)	(0.0268)
Large firm (≥100)	−0.0636	0.0274	−0.0910*
	(0.0423)	(0.0310)	(0.0501)
Outage duration (hrs) × Medium firm (20–99)	0.0025	−0.0053	0.0077
	(0.0049)	(0.0034)	(0.0046)
Outages per month × Medium firm (20–99)	0.0012	−0.0006	0.0018
	(0.0025)	(0.0008)	(0.0022)
Outage duration (hrs) × Large firm (≥100)	0.0020	−0.0067	0.0087
	(0.0159)	(0.0063)	(0.0193)
Outages per month × Large firm (≥100)	0.0056	−0.0030	0.0086*
	(0.0038)	(0.0024)	(0.0049)
Constant	−0.0261	−0.0192	−0.0069
	(0.0576)	(0.0341)	(0.0667)
Observations	11,211	11,211	11,211
Country FE	Yes	Yes	Yes
Sector FE	Yes	Yes	Yes
Adjusted R^2	0.2853	0.1714	0.2009
Wild-cluster p (interactions, joint)	0.7240	0.1899	0.3153

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Table A.4: *continued*

	Generator **(1)**	**Solar** **(2)**	**Gap** **(3)**
Wild-cluster p (gap slope, duration)			0.2010
Wild-cluster p (gap slope, frequency)			0.5503

*Notes: Outage exposure interacted with firm size (small is the reference); Gap = generator-solar, SE clustered by country. * p<0.10, ** p<0.05, *** p<0.01.*

Table A.5: Regional Heterogeneity

	Generator (1)	**Solar** (2)	**Gap** (3)
Outage duration (hrs)	0.0104***	0.0029	0.0074**
	(0.0028)	(0.0027)	(0.0030)
Outages per month	−0.0005	−0.0015***	0.0010
	(0.0022)	(0.0005)	(0.0023)
Employees (ln)	0.1146***	0.0390***	0.0756***
	(0.0113)	(0.0067)	(0.0120)
Firm age (ln)	0.0375***	−0.0067	0.0443***
	(0.0122)	(0.0057)	(0.0144)
Exporter (=1)	−0.0344	0.0737***	−0.1081***
	(0.0330)	(0.0237)	(0.0375)
Foreign-owned (>10%)	0.0931***	0.0206	0.0724**
	(0.0257)	(0.0211)	(0.0301)
In capital city (=1)	0.0050	0.0013	0.0037
	(0.0303)	(0.0294)	(0.0278)
Outage duration (hrs) × East Asia	0.0104	0.0164**	−0.0060
	(0.0075)	(0.0063)	(0.0119)
Outages per month × East Asia	0.0040	−0.0030	0.0070
	(0.0079)	(0.0035)	(0.0055)
Outage duration (hrs) × South Asia	−0.0215	−0.0091	−0.0124
	(0.0149)	(0.0056)	(0.0153)
Outages per month × South Asia	0.0043*	0.0024***	0.0019
	(0.0022)	(0.0005)	(0.0023)
Outage duration (hrs) × MENA	−0.0090**	−0.0061*	−0.0029
	(0.0038)	(0.0035)	(0.0049)
Outages per month × MENA	0.0078*	0.0015*	0.0063
	(0.0039)	(0.0009)	(0.0043)
Outage duration (hrs) × Latin America	−0.0004	−0.0016	0.0012
	(0.0082)	(0.0043)	(0.0090)
Outages per month × Latin America	0.0080	0.0045	0.0035
	(0.0072)	(0.0030)	(0.0049)
Outage duration (hrs) × Europe & Central Asia	0.0044	0.0209	−0.0165
	(0.0115)	(0.0133)	(0.0242)
Outages per month × Europe & Central Asia	0.0254*	−0.0035	0.0289
	(0.0143)	(0.0048)	(0.0190)
Constant	−0.0249	−0.0181	−0.0068
	(0.0510)	(0.0325)	(0.0604)
Observations	11,252	11,252	11,252

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Table A.5: *continued*

	Generator (1)	**Solar (2)**	**Gap (3)**
Country FE	Yes	Yes	Yes
Sector FE	Yes	Yes	Yes
Adjusted R^2	0.2862	0.1752	0.2010
Wild-cluster p (interactions, joint)	0.1742	0.7259	0.6080
Wild-cluster p (gap slope, duration)			0.0383
Wild-cluster p (gap slope, frequency)			0.6944
Wild-cluster p (duration x East Asia)		0.3008	

*Notes: Outage exposure interacted with region (Sub-Saharan Africa is the reference); Gap = generator-solar, SE clustered by country. * p<0.10, ** p<0.05, *** p<0.01.*

Table A.6: The Generator-Solar Asymmetry across Alternative Outage Measures

	Generator (=1)				**Solar (=1)**			
	(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**	**(8)**
Outage duration (hrs)	0.0116***				0.0039			
	(0.0024)				(0.0025)			
Outages per month		0.0018				−0.0007		
		(0.0024)				(0.0007)		
Outages per month × Outage duration, hrs			0.0005**				0.0001	
			(0.0002)				(0.0001)	
Any outage (=1)				0.1388***				−0.0136
				(0.0312)				(0.0170)
Employees (ln)	0.1150***	0.1139***	0.1144***	0.1129***	0.0393***	0.0388***	0.0390***	0.0389***
	(0.0114)	(0.0115)	(0.0114)	(0.0114)	(0.0065)	(0.0065)	(0.0065)	(0.0065)
Firm age (ln)	0.0375***	0.0393***	0.0394***	0.0363***	−0.0064	−0.0061	−0.0058	−0.0057
	(0.0118)	(0.0118)	(0.0117)	(0.0112)	(0.0060)	(0.0059)	(0.0060)	(0.0060)
Exporter (=1)	−0.0369	−0.0383	−0.0376	−0.0357	0.0747***	0.0733***	0.0742***	0.0734***
	(0.0337)	(0.0346)	(0.0342)	(0.0324)	(0.0235)	(0.0240)	(0.0238)	(0.0238)
Foreign-owned (>10%)	0.0935***	0.0913***	0.0891***	0.0929***	0.0186	0.0192	0.0177	0.0185
	(0.0253)	(0.0246)	(0.0243)	(0.0223)	(0.0211)	(0.0210)	(0.0216)	(0.0208)
In capital city (=1)	0.0007	0.0005	−0.0003	0.0063	0.0006	−0.0003	0.0002	−0.0006
	(0.0299)	(0.0308)	(0.0302)	(0.0304)	(0.0289)	(0.0294)	(0.0290)	(0.0295)
Constant	−0.0232	−0.0106	−0.0144	−0.0797	0.0086	0.0211	0.0138	0.0246
	(0.0413)	(0.0433)	(0.0404)	(0.0474)	(0.0247)	(0.0239)	(0.0237)	(0.0267)
Observations	11,252	11,252	11,252	11,252	11,252	11,252	11,252	11,252
Country FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Sector FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Adjusted R^2	0.2819	0.2774	0.2788	0.2906	0.1714	0.1702	0.1701	0.1702

Notes: Each column regresses adoption on one outage measure; SE clustered by country. * p<0.10, ** p<0.05, *** p<0.01.

Table A.7: The Generator-Solar Asymmetry (Average Marginal Effect)

	Generator (=1) (1)	**Solar (=1)** (2)	**Energy mgmt (=1)** (3)
Outage duration (hrs)	0.0126***	0.0024*	0.0061
	(0.0033)	(0.0013)	(0.0037)
Outages per month	0.0008	−0.0005	−0.0010
	(0.0018)	(0.0004)	(0.0018)
Employees (ln)	0.1112***	0.0354***	0.0650***
	(0.0101)	(0.0056)	(0.0095)
Firm age (ln)	0.0378***	−0.0056	−0.0053
	(0.0123)	(0.0060)	(0.0092)
Exporter (=1)	−0.0304	0.0586***	0.0398
	(0.0311)	(0.0138)	(0.0387)
Foreign-owned (>10%)	0.0872***	0.0177	0.0681**
	(0.0223)	(0.0171)	(0.0347)
In capital city (=1)	−0.0005	0.0008	−0.0125
	(0.0291)	(0.0269)	(0.0254)
Observations	11,252	11,252	11,252
Country FE	Yes	Yes	Yes
Sector FE	Yes	Yes	Yes

Notes: Average marginal effects from a firm-level logit; SE clustered by country. * p<0.10, ** p<0.05, *** p<0.01.

Table A.8: The Generator-Solar Asymmetry Excluding Influential Countries

	Generator (=1)			Solar (=1)		
	Full sample	Excluding Afghanistan	Excluding Egypt, Kenya & Nigeria	Full sample	Excluding Afghanistan	Excluding Egypt, Kenya & Nigeria
	(1)	(2)	(3)	(4)	(5)	(6)
Outage duration (hrs)	0.0111***	0.0118***	0.0120***	0.0043*	0.0048*	0.0055*
	(0.0026)	(0.0027)	(0.0034)	(0.0025)	(0.0026)	(0.0031)
Outages per month	0.0011	0.0005	0.0005	−0.0009	−0.0015***	−0.0009
	(0.0022)	(0.0025)	(0.0022)	(0.0006)	(0.0005)	(0.0006)
Employees (ln)	0.1150***	0.1160***	0.1191***	0.0392***	0.0392***	0.0382***
	(0.0114)	(0.0117)	(0.0118)	(0.0065)	(0.0067)	(0.0068)
Firm age (ln)	0.0378***	0.0389***	0.0434***	−0.0067	−0.0084	−0.0048
	(0.0118)	(0.0121)	(0.0126)	(0.0059)	(0.0058)	(0.0062)
Exporter (=1)	−0.0362	−0.0400	−0.0407	0.0741***	0.0706***	0.0772***
	(0.0337)	(0.0345)	(0.0369)	(0.0237)	(0.0240)	(0.0250)
Foreign-owned (>10%)	0.0923***	0.0922***	0.0983***	0.0196	0.0201	0.0168
	(0.0250)	(0.0256)	(0.0257)	(0.0212)	(0.0213)	(0.0223)
In capital city (=1)	0.0014	−0.0021	−0.0043	0.0000	−0.0030	0.0048
	(0.0301)	(0.0311)	(0.0329)	(0.0291)	(0.0301)	(0.0314)
Constant	−0.0233	−0.0332	−0.0515	−0.0174	−0.0111	−0.0272
	(0.0520)	(0.0539)	(0.0543)	(0.0335)	(0.0301)	(0.0370)
Observations	11,252	10,861	8,450	11,252	10,861	8,450
Adjusted R^2	0.2822	0.2837	0.2614	0.1719	0.1436	0.1768

Notes: The main result re-estimated dropping the highest-solar economy and then the three largest samples; SE clustered by country. * p<0.10, ** p<0.05, *** p<0.01.

Table A.9: The Generator-Solar Asymmetry with Instrumented Outage Exposure

	Generator (=1)			Solar (=1)		
	OLS	IV	IV + controls	OLS	IV	IV + controls
	(1)	(2)	(3)	(4)	(5)	(6)
Outage duration (hrs)	0.0111***	0.0842**	0.0825**	0.0043	0.0629	0.0624
	(0.0026)	(0.0339)	(0.0349)	(0.0025)	(0.0539)	(0.0531)
Outages per month	0.0011	0.0029	0.0025	−0.0009	0.0056	0.0055
	(0.0022)	(0.0047)	(0.0048)	(0.0006)	(0.0046)	(0.0045)
Employees (ln)	0.1149***	0.1224***	0.1221***	0.0393***	0.0457***	0.0455***
	(0.0114)	(0.0116)	(0.0116)	(0.0065)	(0.0099)	(0.0099)
Firm age (ln)	0.0380***	0.0299**	0.0293**	−0.0067	−0.0117	−0.0120
	(0.0118)	(0.0138)	(0.0137)	(0.0059)	(0.0107)	(0.0106)
Exporter (=1)	−0.0368	−0.0188	−0.0219	0.0746***	0.0928***	0.0911***
	(0.0340)	(0.0337)	(0.0331)	(0.0238)	(0.0272)	(0.0271)
Foreign-owned (>10%)	0.0927***	0.0936***	0.0932***	0.0194	0.0148	0.0145
	(0.0250)	(0.0290)	(0.0289)	(0.0213)	(0.0304)	(0.0302)
In capital city (=1)	0.0011	0.0112	0.0143	0.0001	0.0115	0.0104
	(0.0301)	(0.0304)	(0.0316)	(0.0291)	(0.0322)	(0.0307)
Constant	−0.0237	0.0978	0.1652	−0.0176	0.2010	0.1867
	(0.0521)	(0.1019)	(0.1281)	(0.0335)	(0.1438)	(0.1991)
Observations	11,243	11,243	11,243	11,243	11,243	11,243
Country FE	Yes	Yes	Yes	Yes	Yes	Yes
Sector FE	Yes	Yes	Yes	Yes	Yes	Yes
Nearby firm size and export controls		No	Yes		No	Yes
First-stage F (duration)		4.9			4.9	
First-stage F (frequency)		126.9			126.9	
Kleibergen-Paap rk F		3.4			3.4	
Endogeneity (DWH) p		0.286			0.498	

Notes: Two-stage least squares instrumenting exposure with the leave-out mean exposure of other firms in the country×locality; SE clustered by country. * p<0.10, ** p<0.05, *** p<0.01.

Table A.10: Outage Response by Firm-Reported Court Quality

	Generator (1)	**Solar** (2)	**Gap** (3)
Outage duration (hrs)	0.0108***	0.0036	0.0072**
	(0.0028)	(0.0024)	(0.0033)
Outages per month	0.0014	−0.0009	0.0023
	(0.0023)	(0.0006)	(0.0022)
Court quality index (SD)	0.0005	0.0025	−0.0020
	(0.0075)	(0.0077)	(0.0103)
Outage duration (hrs) × Court quality index	−0.0003	−0.0004	0.0001
	(0.0028)	(0.0023)	(0.0031)
Outages per month × Court quality index	−0.0002	0.0001	−0.0002
	(0.0007)	(0.0002)	(0.0008)
Employees (ln)	0.1149***	0.0386***	0.0763***
	(0.0115)	(0.0066)	(0.0120)
Firm age (ln)	0.0410***	−0.0056	0.0467***
	(0.0127)	(0.0060)	(0.0149)
Exporter (=1)	−0.0381	0.0739***	−0.1120***
	(0.0347)	(0.0242)	(0.0395)
Foreign-owned (>10%)	0.0913***	0.0203	0.0711**
	(0.0255)	(0.0211)	(0.0297)
In capital city (=1)	0.0033	0.0012	0.0022
	(0.0302)	(0.0299)	(0.0282)
Constant	−0.0306	−0.0173	−0.0133
	(0.0536)	(0.0337)	(0.0612)
Observations	11,130	11,130	11,130
Country FE	Yes	Yes	Yes
Sector FE	Yes	Yes	Yes
Adjusted R^2	0.2825	0.1782	0.2011
Wild-cluster p (duration interaction)	0.9313	0.9084	0.9685
Wild-cluster p (frequency interaction)	0.8925	0.7092	0.8271

*Notes: Court quality index = mean of the firm's standardised answers on courts as an obstacle to operations (reversed) and courts being independent and impartial in commercial disputes, in SD units (higher = better courts); Gap = generator-solar, SE clustered by country. * p<0.10, ** p<0.05, *** p<0.01.*

Appendix B. Variable Definitions

Table B.1: Variable Definitions and Sources

Variable	Definition and coding	Source
Panel A. Energy outcomes		
Has generator (=1)	1 if the establishment owned or shared a generator in the last fiscal year, 0 otherwise	WBES c10
Has solar (=1)	1 if the establishment used on-site solar panels to generate electricity in the last fiscal year, 0 otherwise	WBES c43
Generator % of electricity	Percentage of the establishment's electricity from its own or shared generator, 0 to 100, with 0 for firms without a generator	WBES c11
Solar % of electricity	Percentage of the establishment's electricity from on-site solar, 0 to 100, with 0 for non-adopters	WBES c44
Self-generation portfolio	Three categories combining the two indicators, namely generator only, solar only, and both	WBES c10, c43
Energy management (=1)	1 if the firm reports adopting energy management measures	WBES ge8d
CO2 monitoring (=1)	1 if the firm monitors its own carbon dioxide emissions	WBES ge7
Panel B. Outage exposure		
Outages per month	Number of power outages in a typical month, with 0 for firms reporting no outages in the last fiscal year	WBES c6, c7
Outage duration (hrs)	Typical length of an outage in hours (hours plus minutes divided by 60), with 0 for firms reporting no outages	WBES c6, c8
Leave-out-mean instruments	Average outage duration and frequency reported by all other firms in the same country and locality	WBES c7, c8
Panel C. Firm characteristics		
Employees (ln)	Natural logarithm of permanent full-time employees at the end of the last fiscal year	WBES l1
Firm age (ln)	Natural logarithm of one plus the number of years the establishment has been operating	WBES b5
Exporter (=1)	1 if direct exports exceed 0 percent of the establishment's sales	WBES d3c
Foreign-owned (>10%)	1 if private foreign owners hold more than 10 percent of the firm	WBES b2b

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Table B.1: *continued*

Variable	Definition and coding	Source
In capital city (=1)	1 if the establishment is located in the capital city	WBES a3b
Quality certification (=1)	1 if the establishment holds an internationally recognised quality certification	WBES b8
Has website (=1)	1 if the establishment has its own website	WBES c22b
Manager experience (ln)	Natural logarithm of one plus the top manager's years of experience in the sector	WBES b7
Offers training (=1)	1 if the establishment ran formal training programmes for permanent full-time employees	WBES l10
Panel D. Finance and courts		
Credit constrained (=1)	1 if fully or partially credit constrained, 0 if unconstrained (definitions in Section 4.4)	ES Indicators
Has bank loan/credit line (=1)	1 if the establishment has a loan or line of credit from a financial institution	ES Indicators
Invested in fixed assets (=1)	1 if the establishment purchased fixed assets in the last fiscal year	WBES k4
Investment externally financed (=1)	Among firms that invested, 1 if less than 100 percent of fixed-asset purchases was financed internally	ES Indicators
Finance obstacle (0–4)	Degree to which access to finance is an obstacle, 0 no obstacle, 1 minor, 2 moderate, 3 major, 4 very severe	WBES k30
Country credit-deep (=1)	1 if domestic credit to the private sector (percent of GDP), most recent year, is above the developing-sample median	WDI
Courts an obstacle to operations (0–4)	Degree to which courts are an obstacle to current operations, 0 no obstacle, 1 minor, 2 moderate, 3 major, 4 very severe	WBES h30
Courts independent and impartial (1–4)	Agreement that courts are independent and impartial in resolving commercial disputes, 1 strongly disagree, 2 tend to disagree, 3 tend to agree, 4 strongly agree	WBES j31
Court quality index (SD)	Mean of the standardised court items, with the obstacle item reversed, rescaled to mean 0 and SD 1, higher values indicating better courts	WBES h30, j31

Notes: WBES codes refer to questions in the Enterprise Surveys standard questionnaire. ES Indicators = World Bank Enterprise Surveys Indicators Database. WDI = World Development Indicators, series FS.AST.PRVT.GD.ZS.

Figures

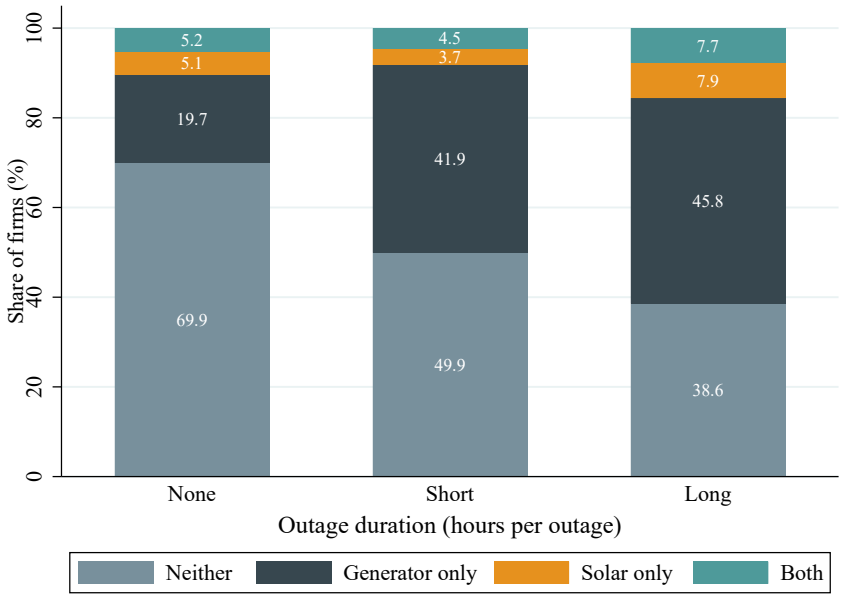


Figure 1. Self-generation by level of outage exposure

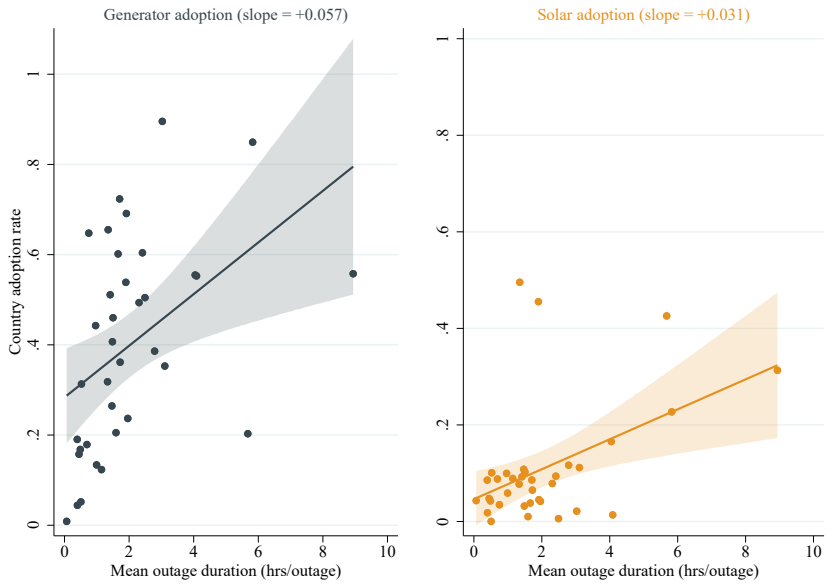


Figure 2. Solar adoption and grid reliability across economies

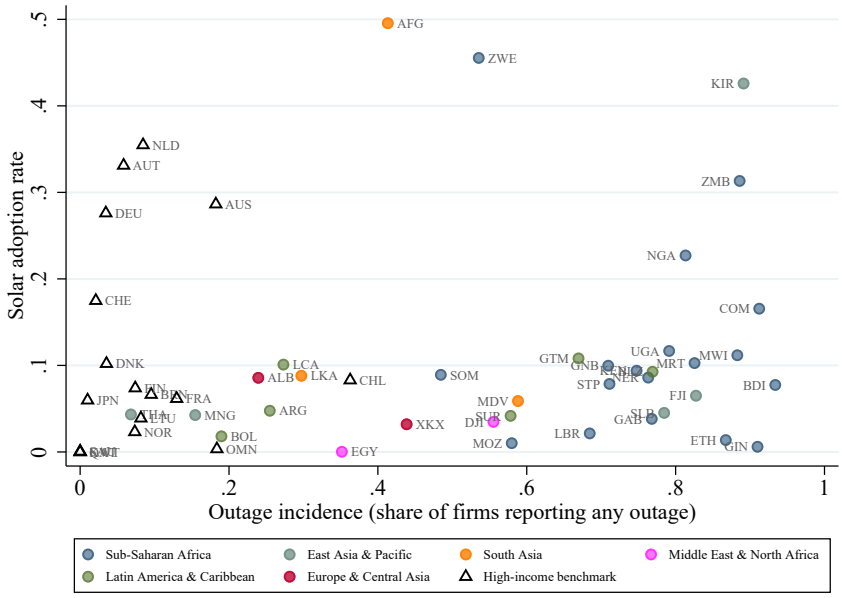


Figure 3. Generator and solar adoption against outage duration, by country

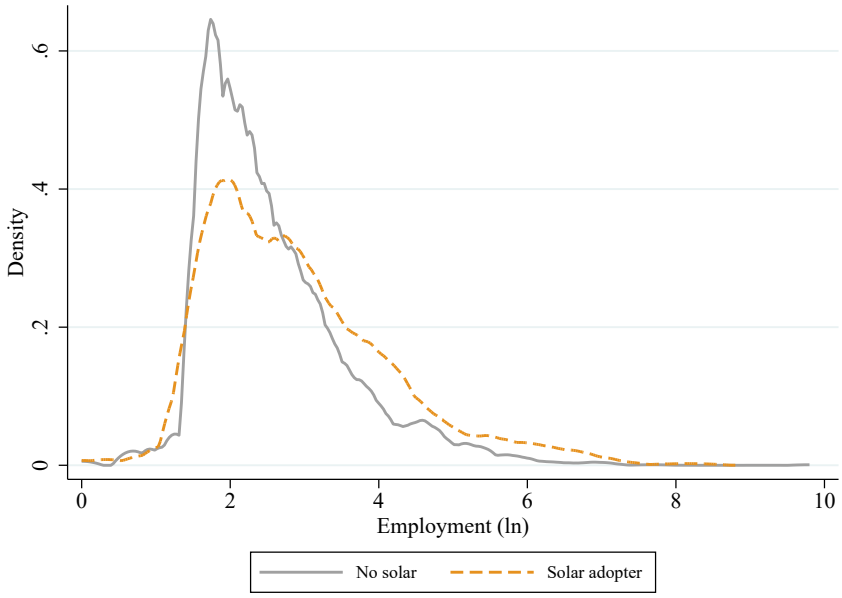


Figure 4. Distribution of firm size by solar adoption

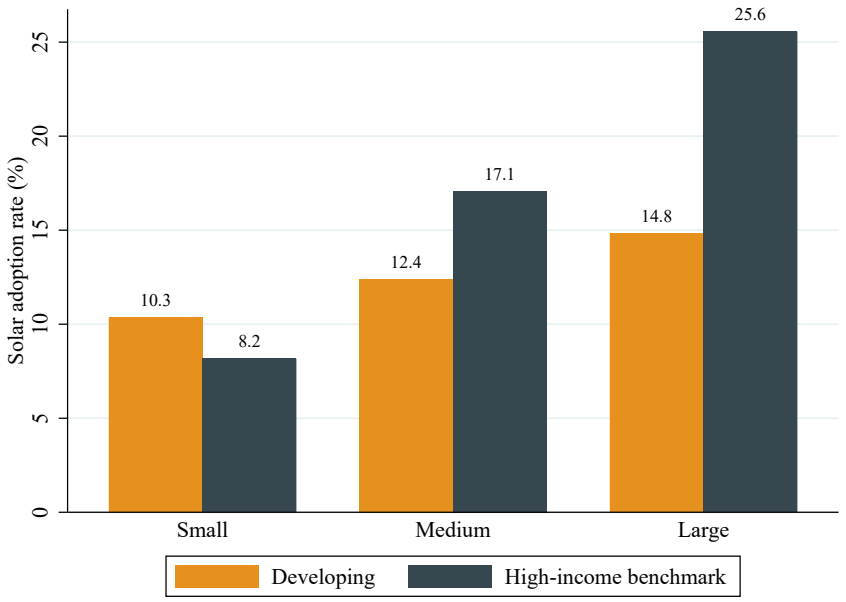


Figure 5. Solar adoption by firm-size class, developing and high-income benchmark