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# Energy prices, generators, and the (environmental) performance of manufacturing firms: Evidence from Indonesia

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## Abstract

Generator use is widespread among firms in developing and emerging economies, including Indonesia, shielding them from unreliable and insufficient electricity supply. This, however, makes these firms more vulnerable to fuel price increases, as well as more emission intensive. We exploit variation in policy-induced fossil fuel and electricity tariff adjustments using a rich panel data set of large manufacturing firms to estimate the impact of energy price increases on generator-reliant firms versus those not relying on generators. We find that generator-reliant firms reduce output and value added by around 0.6–0.8 percent in response to a ten percent fossil fuel price increase, and adjust inputs flexibly: Material input and labor demand fall by 0.7 and 0.5 percent, respectively. Because firms dis-adopt generator use in response to higher fuel prices, emission and energy intensity of production declines by around 0.7–0.8 percent on average. Electricity price increases, in contrast, are absorbed and do not lead to differential input adjustments in the short term. As firms that use generators also have a higher cost share of grid electricity, value added and labor productivity decline to a greater extent compared to other firms. In addition, rising electricity prices further incentivize inefficient generator use.

*JEL codes:* L60, O14, Q41

*Keywords:* energy prices, manufacturing sector, firm performance, emission intensity, generators

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# 1 Introduction

Firms in developing countries often choose to self-generate electricity to mitigate negative effects of unreliable electricity supply (Alby et al., 2012). The positive effects of generator use on firm performance have been extensively studied in the literature. The other side of the coin, namely that the reliance on generators for electricity production makes firms especially susceptible to fuel price increases, has not received any attention so far. This is despite the fact that many especially large firms in developing countries use generators, which puts a large part of the economy at risk of competitiveness losses. Further, inefficiently produced electricity from generators is associated with very high energy and emission intensities of production.

Generator use thus is a prime example for a technology investment decision that represents a trade-off between economic development goals and climate change mitigation concerns. In this study, we aim to estimate the impact of rising energy prices on firms that use generators versus those that do not, and thereby empirically investigate whether generator reliance leads to relative competitiveness losses when fossil fuel prices rise. Further, we estimate the impact on both energy and emission intensities to examine the extent of emission reduction due to potential dis-adoption of generator use. This is especially relevant for Indonesia, the 8th largest emitter of carbon dioxide worldwide according to the Global Carbon Atlas.<sup>1</sup>

A growing strand of literature estimates the impact of unreliable electricity supply on firm performance in developing countries. The majority of studies point to the role of generators as a means to cushion negative effects of shortages or outages (Falentina and Resosudarmo, 2019; Cole et al., 2018; Fisher-Vanden et al., 2015). Allcott et al. (2016), for example, exploit exogenous variation in hydroelectric power availability to estimate the effect of shortages on performance measures of Indian manufacturing firms. Average reported shortages decrease revenue and producer surplus by 5–10 percent, while productivity losses are much smaller. Generator ownership is, however, associated with smaller impacts.

Many other studies measure the impact of energy price increases on firm performance.<sup>2</sup> This study is closely related to empirical studies that investigate the impact of the emission trading scheme of the European Union, which also quantify both competitiveness outcomes and emission intensity effects of policy-induced energy price increases. Dechezlepretre et al. (2018), for example, find that rising emission prices caused by the cap-and-trade scheme reduced emissions of firms by around 10 percent, but find no effects on firm performance. A recent contribution is the study of Colmer et al. (2020), who find that regulated firms in France reduce emission by 8–12 percent via targeted investments, rather than by reducing production.

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<sup>1</sup>The emission ranking is based on territorial CO<sub>2</sub> emissions, not on consumption-based emissions.

<sup>2</sup>See Arlinghaus (2015) for an overview of earlier papers.

Studies that investigate the trade-off between firm performance and emission intensity in emerging or developing countries, however, is scarce. An exception is the study by Abeberese (2017), who exploits exogenous variation in electricity prices to estimate the impact on Indian manufacturing firms. She finds that firms switch to less electricity intensive production processes, have lower output and productivity growth rates and decrease their machine intensity. To the best of our knowledge, ours is the first study that looks at the impact of rising energy price increases on firm performance and emission intensity with a focus on generator use.

This paper proceeds as follows: Section 2 provides an overview of data sources, energy price policy and generator use in Indonesia, and derives empirical hypotheses. Section 3 describes the empirical model. Estimation results are presented and discussed in Section 4, while Section 5 concludes.

## 2 Data and hypotheses

### 2.1 Data sources

We use the annual manufacturing census of medium size and large manufacturing establishments that employ at least 20 workers, conducted by Statistics Indonesia (Badan Pusat Statistik, BPS). This census records basic balance sheet information for each firm and includes a series of questions on energy usage and related expenditures. We link the yearly survey rounds into a panel of XXX manufacturing establishments over 16 years (2000 to 2015). The data is separately recorded for each plant and no ownership linkages between plants are recorded; for the sake of simplicity, we refer to all establishments as firms.

Fuel tariff data are obtained from several different sources (Chelminski, 2018; Husar and Kitt, 2016; Kojima, 2016; Beaton and Lonton, 2010). Electricity tariff data for 2000 to 2015 combines data directly provided by the PLN (*Perusahaan Listrik Negara*) office in Jakarta with freely available presidential decrees.<sup>3</sup>

We obtain information on electricity generation (2000–2015) and grid quality (2010–2015) from Handbooks of Energy and Economic Statistics in Indonesia, and several statistical handbooks published by the PLN (*Statistik Listrik PLN*). Using information on electricity generation, we estimate the energy content of one kWh of electricity produced or distributed by PLN using the tier 1-method proposed by IPCC (2006). For electricity produced by PLN, computation is straightforward: We divide the energy content per input fuel by electricity produced by that input to get an average estimate of energy content per kWh. We do not observe fuel inputs for electricity

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<sup>3</sup>PLN is a government-owned corporation that is responsible for the major share of electricity generation and its distribution. It produces around three-quarters of the total electricity distributed by it, while another 22% are provided by independent power producers via purchase agreements with PLN (IEA, 2015).

provided by independent producers, and we estimate energy content assuming that these providers operate under similar conditions as PLN, i.e., fuel consumption per kWh is the same for both PLN and independently provided electricity. Emission intensity computation as kgCO<sub>2</sub>e per kWh with appropriate conversion factors between physical fuel units and emissions is straightforward.

## 2.2 Energy prices

The price variation we exploit in this analysis stems from changes in Indonesia's fossil fuel subsidy system, as well as from the price policy of PLN. We argue that most tariff adjustments are plausibly exogenous to firm performance.

In 2004, Indonesia's oil imports exceeded its oil exports for the first time since it started its oil production. As a result, fuel subsidies amounted to up to 24 percent of the government expenditures. The resulting fiscal pressure was the major cause of tariff adjustments by over 100 percent for diesel and gasoline in 2005, which were introduced despite a wide opposition to these reforms (Chelminski, 2018). The reforms also led to the development of a black market that served residential and business customers without access to subsidized fuel (Chelminski, 2018). This is reflected by the close alignment of observed average diesel prices and official tariff rates (Figure 1). Since fuel tariffs were raised in opposition to interest groups and on the basis of fiscal concerns, we argue that changes in the Indonesian tariff policies left relatively little possibility for endogenous response of policy makers to firm performance measures and affected all firms alike. Changes in the official tariff rates have also affected the black market price of fossil fuels, as indicated by the close alignment of official tariffs and observed average prices. In the years after 2012, the Indonesian currency devalued dramatically, while world market prices for oil remained relatively stable. This forced decision makers to increase tariffs gradually between 2013 and 2015. Thus, fuel tariff adjustments in these years might additionally be correlated with firm performance through their correlation with exchange rate movements. As this may lead to a potential omitted variable bias, we will test for the robustness of our results when cutting off the sample after 2013, before the exchange rate adjustments started.

The Indonesian government is also responsible for setting electricity tariffs, as the parliament gives final approval to tariff changes. These are divided into four categories for industrial customers. The tariff selection of firms depends on the electric power of electricity supply: firms with an electric power demand between 0.45 kVA and 14 kVA fall into one of the five subcategories of category 1, a power demand between 14 kVA–200 kVA falls into category 2, 200 kVA–30,000 into category 3, and above that into category 4. As electric power is the product of the electric potential  $U$  of the power connection of the firm and the electric current  $I$ , it depends on both the type of power connection and the amount of electricity needed to power all machinery. Thus,

larger firms typically belong in higher tariff categories. Further, the tariff has two components for all categories: (1) a variable tariff that depends on the amount of electricity (IDR/kWh) and (2) a monthly load fee. In 2010, the calculation of the second component of categories 2 to 4 was changed from a fixed fee to a variable tariff dependent upon kWh consumed, which made electricity in effect more expensive for most customers and decoupled the marginal price of electricity from consumed quantities. In subsequent years, the tariff was regularly raised.

In our firm-level data, we observe both kWh consumed and the total costs of electricity, but not which tariffs apply to each firm. To assign a tariff to each firm, we compute the average price observed in tariff categories 2 to 4, excluding category 1 that applies to small-scale customers, which provides an average estimate of electricity price changes over time. In Figure 1, we plot the average price observed in the firm census, the average variable tariff rate (collected from PLN and freely available presidential decrees), as well as an estimate of the price dynamics over years, calculated by summing up the variable tariff rate times kWh and monthly load fee for the years 2000-2010. After 2010, the variable tariff applies twice per kWh. The observed average electricity price is higher in almost all years, reflecting an imprecision of our price estimation since a load factor of  $1.4 < k < 2$  is applied in times of high electricity demand, which we do not directly account for. Further, since 2010 a tariff rate is charged for the cost of excess reactive power usage (kVArh) in cases when the average power factor is below 85% in a given month. Together, these two factors are likely responsible for the difference between average observed and estimated price, as well as price fluctuations. However, tariff increases are well reflected in observed prices, and thus represent plausible exogenous variation in electricity prices. Figure 2 plots electricity tariffs over time for the categories 2 to 4 separately. Tariff adjustments are highly collinear except in 2015, when the variable tariff for larger customers (categories 3 and 4) increased sharply, while the tariff for customers in category 2 remained constant.

Results of a regression of observed fuel and electricity prices on tariffs in Table 1 show a robust one-to-one correlation with high R-squared values. Estimated electricity tariffs predict prices well, although the R-squared values are lower, reflecting endogenous variation in actual electricity prices at the firm level. For the period 2000 to 2009, we rely on the average tariff rate instead of the estimated price as the latter is endogenously influenced by the quantity consumed in this period. This is because in this period, the monthly load fee was a fixed component, and thus the average price declined with the quantity consumed.

## 2.3 Generator use

Alby et al. (2012) develop a formal model of a firms' decision to invest in a generator, and come up with three determinants of generator use: The size of the firm (or the firms' net worth) as a

measure of credit constraints, the quality of electricity supply (that is, frequency and duration of blackouts), and sector-specific sensitivity to electricity supply quality (measured as sector-level cost-share of electricity expenditure). Their model predicts that in sectors with a high electricity sensitivity, average firm size increases with the number of outages. This is because smaller firms cannot afford to invest in generators, and thus either exit the market or do not enter to begin with. We argue that the decision to invest in a generator is also influenced by relative prices of fuels and electricity.

In the data at hand, we observe whether a firm used generators in a given year, the number of generators used, as well as the total installed capacity. As predicted by Alby et al. (2012), firms that use generators are on average larger in terms of capital stock, number of workers, total sales and value added, and more productive in terms of value added per worker (see Table 2). They are also around 60 percent more emission and energy intensive per monetary unit of value added. We further observe that ownership rates and average installed capacity are highly collinear with the price movements described above (see Figure 3). The share of firms that use generators drops after the stark fuel price increases in late 2005. Simultaneously, average installed capacity increases, probably due to a selection effect as firms that own fewer generators dropped out of generator use. Starting around 2010, when electricity tariffs were adjusted upwards, both the share of firms that own generators, as well as average installed capacity increases. We further observe a very sharp increase in average installed capacity in 2015, the same year the tariff for large customers increased sharply (compare with Figure 2).<sup>4</sup>

## 2.4 Empirical hypotheses

Economic theory suggests several response options to rising relative prices of energy, given that firms want to maintain current production levels: Firms could (1) decide not to act, which would lead to direct profit losses and lower value added values, *ceteris paribus*; (2) substitute towards alternative energy sources or inputs if production technology allows; (3) invest in more resource efficient technology to a larger extent; (4) increase efficiency by optimizing production processes. Of course, adjustments could also affect total production via a decrease in quantity produced or by diversifying the production portfolio to less fuel-intensive products (as Abeberese (2017) found for Indian firms, on average).

Many firms in Indonesia rely on generators for electricity production. This makes fuel price increases special for these firms, for two reasons: First, they are likely to have a higher energy

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<sup>4</sup>The increase in capacity installed in 2015 does not seem to be driven by grid electricity quality deterioration. Common grid performance indicators collected at the provincial level—system average interruption downtime frequency index (saifi) and system average interruption downtime duration index (saidi)—do not differ noticeably in 2015 compared to the period 2010 to 2014. The data were collected from PLN statistical yearbooks, and are not available for earlier years.

intensity due to efficiency losses of generators, and thus have higher cost shares of fossil fuels compared to firms not relying on generators. Second, fuel and electricity price changes drive their decisions to demand and supply electricity, and will thus also affect the decision to start, continue, or stop using a generator. They face larger potential cost increases due to fuel price increases as compared to firms that do not use generators, which results in a competitive disadvantage.

In the short run, we expect fuel price increases to reduce the firms' value added as well as their sales if they cannot fully absorb the relative price shock. Negative effects on productivity (growth) are possible if firms have to restructure their energy supply towards the less reliable grid electricity, for example. At the same time, investments in more energy efficient technology might increase productivity (growth). The expected effect of electricity price movements is ambiguous. When tariffs rise, this increases the relative price of grid-generated electricity as compared to self-generated electricity. This will increase the probability that a firm uses a generator and firms will also raise the share of self-produced electricity. For firms that already produce large shares of electricity themselves, price increases will lead to relatively lower cost increases as compared to other firms. However, firms using generators are also those that consume more electricity and should be more "sensitive" to the quality of electricity supply (Alby et al., 2012). When firms have limited possibilities to substitute self-generation for grid electricity to a sufficient extent, this will have negative effects on competitiveness outcomes.

### 3 Empirical model

Our empirical model compares the effects of electricity price increases in two different groups of firms, those relying on generators and those not. As tariff increases affect all firms simultaneously, their effects cannot be distinguished from a whole range of common policy shocks and macroeconomic fluctuations, but previous investment decisions into electricity generating technologies will affect how firms adjust to such price changes. For instance, descriptive trends in Figures 1 and 3 show that with the stark price increase in 2005, the share of firms with generator ownership declined substantially, and increased again with electricity tariff increases.

A first (naive) regression specification uses the full sample and interacts a measure of generator reliance with current prices of diesel fuel,  $D_t$ , and electricity,  $E_t$ . As generator ownership may directly respond to price increases in year  $t$ , our main analysis lags the measures of generator reliance. We proxy for generator reliance by past generator ownership  $G_{isd[t-1,t-5]}$ , which is an indicator variable that takes the value of one if a firm has reported using a generator at least once in the past five years. Using the past five years provides a more robust measure of a firm's past reliance on generated electricity than only using generator use in  $t - 1$ , which may have been influenced by very recent price increases. We thus estimate the differential effect of fuel and electricity tariff



changes across firms with and without generator ownership, relying on the following reduced-form regression equation:

$$y_{isdt} = \beta_0 + \beta_1 G_{isd[t-1,t-5]} + \beta_2 G_{isd[t-1,t-5]} \times D_t + \beta_3 G_{isd[t-1,t-5]} \times E_t + \beta_4 L_{isdt-2} + \beta_5 K_{isdt-2} + \beta_6 M_{isdt-2} + \lambda_i + \kappa_{dt} + \gamma_{st} + \epsilon_{isdt}, \quad (1)$$

where  $y_{it}$  denotes a set of dependent variables for a firm  $i$ , operating in sector  $s$ , district  $d$  and year  $t$ , including value added, value added per worker (as a measure of labour productivity), total sales, estimated revenue-based total factor productivity (TFPR), TFPR growth, energy intensity, CO<sub>2</sub> intensity, number of workers and capital stock.<sup>5</sup> All monetary values are deflated by the respective national price index and log-transformed. TFP is estimated using the method proposed by Akerberg et al. (2015) (see appendix for details). All standard errors are clustered at the district level.

Controls include the lagged number of workers,  $L_{isdt-2}$ , lagged capital stock,  $K_{isdt-2}$ , lagged value of material inputs,  $M_{isdt-2}$  (only for the estimation on total sales/gross output), firm fixed effects  $\lambda_i$ , district-year fixed effects  $\kappa_{dt}$  as well as five-digit-sector-year effects  $\gamma_{st}$ . We lag the values of labor, capital and intermediate inputs by two years to reduce the scope of a direct feedback from fuel and electricity prices to input use.<sup>6</sup> Firm fixed effects control for unobserved, time-invariant firm characteristics that might influence firm productivity and other firm outcomes. District-year effects capture a host of local macro-economic dynamics, but also differences over time in the quality of electricity supply, an important determinant of generator ownership. Five-digit-sector-year fixed effects capture a wide range of sector-specific shocks that affect all firms that produce very similar products, and should capture dynamics of sector-specific electricity sensitivity as defined by Alby et al. (2012). The parameter estimate  $\beta_1$  identifies the effect of having become a generator owner in the past, not the effect of being one, as we employ firm fixed effects.

While we control for observable determinants of generator ownership in the above regression (sector and district effects, as well as firm size measured by capital stock and number of workers) generator ownership will be correlated with firm size. Hence, estimates are likely to be biased. To tackle this, we match firms with past generator use to firms without past generator use based on firm size in order to ensure that we compare similar firms to each other (for similar procedures, see e.g., Imbruno and Ketterer, 2018; Arnold et al., 2011; De Loecker, 2007). We model the probability

<sup>5</sup>We exclude  $L_{isdt-2}$  for estimations on value added per worker, and number of workers. We exclude  $K_{isdt-2}$  for the regression estimating capital stock.

<sup>6</sup>The model is estimated using a panel of manufacturing establishments over 18 years (1998 to 2015), which allows us to cover the period from 2000 to 2015, for which tariff data are available.

of using a generator in any given year as follows:

$$P[G_{isd}] = \Phi[h(L_{isd}, K_{isd}, S_s, \kappa_d)], \quad (2)$$

where  $\Phi$  is the cumulative distribution function, and  $h$  is estimated as a function of firm size (labor and capital), a measure of sector-specific electricity sensitivity  $S_s$  (defined as average kWh per value added), and a set of district fixed effects  $\kappa_d$  to control for location specific differences in electricity supply quality. We run a probit model to determine the probability of owning a generator and include second-order polynomial (interaction) terms for both labor and capital to relax the dependence on functional form. The model is estimated for each survey year separately, and we set a caliper distance of 0.01 (chosen by the quality of covariate matching). As anticipated, capital stock, the number of workers, and electricity sensitivity predict past generator ownership in each year (results not reported). After estimation, we determine a single nearest neighbor match for each generator-owning firm based on the estimated propensity score for generator ownership. The resulting sample achieves balance in both capital stock and number of workers, as we find no statistically significant differences (at the usual levels) in means between firms with and without generator use, and standardized differences in means are very low (below 0.01). Lastly, we run the same regressions as before for this matched sample, again controlling for capital and labor, as well as firm, district-year and sector-year fixed effects. Exchange rate movements after 2013 might confound our estimates due to a strong devaluation of the Indonesian currency in the following years that also triggered further tariff increases. Thus, in our final specification, we reduce the matched sample to observations before 2014, and in doing so only use the price variation that is not yet related to currency movements to estimate the effect of energy price increases that were induced only by tariff reforms.

The matching procedure relies on the assumption of a selection on observables (conditional independence assumption, see e.g., Rosenbaum and Rubin, 1983). We compare firms that use a generator with firms that, given objective criteria, "should" also use a generator. The decision of the latter type of firms to not rely on a generator could be related to differences in management styles that are not observed. To the extent that these styles are correlated with reactions to price increases, our estimates will be biased. However, it is highly unlikely that such styles would dominate reactions to energy price increases, as the cost structure likely drives adjustment at the establishment level. Another concern with respect to identification is related to the estimation of both gross output and value added production functions. In the reduced-form regressions, we do not control for productivity shocks that are observed by the firm, but not by us. Thus, estimates of output elasticities with respect to each input (capital, labor and intermediate inputs) are likely biased (Gandhi et al., 2020; Akerberg et al., 2015). This, however, is not a major concern, since

the exact estimation of these elasticities is not what we are after. The price shocks caused by tariff adjustments are plausibly exogenous, and thus the differential effect of these price increases on generator users versus non-users should not depend on current levels of inputs or unobserved idiosyncratic productivity shocks of firms.

## 4 Results

### 4.1 Gross output, value added and (labor) productivity

Estimates of the full sample regressions on sales, value added, labor productivity and TFPR (Tables 3 and 4) indicate that both diesel and electricity tariff increases affect generator-reliant firms negatively compared to firms not using a generator. The effect of both price increases is of similar magnitude: a tariff increase of 10 percent leads to a decrease in sales of 1.0–1.3 percent, a decrease of value added of 0.9–1.0 percent, and a decrease in labor productivity by 0.6–0.7 percent. Results of TFPR indicate that becoming a generator owner is associated with an increase in total factor productivity by about one percent, while both diesel and electricity tariff increases have a negative impact.

Results for the matched sample are different, but point in the same direction. The magnitude of the differential effect of electricity tariff changes reduces in the regression on sales and value added: We now find that firms reduce sales by around 1.0 percent and value added by around 0.6 percent (significant at the ten percent level) for a 10 percent price increases in diesel tariffs. Sales and value added drop by 0.5 percent for electricity tariffs compared to firms of similar size. In contrast to naive regression results, we find no statistically significant effect of diesel tariff increases on labor or total factor productivity. However, the negative impact of electricity tariffs on both productivity measures persists.

Reducing the sample to the period from 2000 to 2013 to rule out that exchange rate movements drive our results again produces slightly different estimates. The negative effect of diesel tariffs on sales persists at around 0.8 percent, while the estimate of electricity tariff increases stays negative, but is now statistically insignificant. The estimated coefficients of both tariff increases on value added become smaller, and both are now statistically significant only at the ten percent level. Labor productivity declines by 0.3 percent for a 10 percent electricity tariff increase (significant at the ten percent level). We find no effect on TFPR in the reduced sample.

These results indicate that firm performance impacts of energy price increases are different for firms using a generator than for firm not using a generator (in the past). Further, relative adjustment differences are of a different nature for diesel and for electricity tariffs. Diesel tariff increases cause reductions in both total sales and to a lesser extent in value added, while electricity tariff increases

tend to cause reductions in valued added and value added per worker compared to firms not using a generator. We will further explore the nature of these different adjustments below.

## 4.2 Energy and emission intensity

Firms that start to use a generator are about 15–20 percent more energy intensive per monetary unit of value added than comparable firms that do not use a generator (Table 5). Diesel tariff increases of 10 percent cause firms that use a generator to be 0.6–0.8 percent less energy intensive because less electricity is self-generated as generator fuel becomes more expensive. These results are robust to both sample matching and reduction, while the negative coefficient for electricity tariff increases becomes statistically insignificant when moving away from the naive regression. Results for emission intensity mirror results for energy intensity, with slightly larger point estimates. This is expected and confirms that the higher GHG emission intensity is attributable to the relative inefficiency of generators vis-à-vis electricity generation of PLN, even though environmental performance of grid electricity deteriorated in recent years due to a rising share of coal as fuel in electricity generation. [Maybe add graph, and introduce this issue earlier, or delete the subclause].

## 4.3 Labor, capital and materials

The size of the labor force reacts strongly to generator use (Table 6). Firms that start using a generator have an about 6 percent larger workforce than firms not using a generator. Conversely, firms that use generators flexibly adjust their labor input: We find that these firms decrease the labor force by about 0.5 percent for a 10 percent diesel tariff increase compared to other firms. We find no effects for electricity tariff increases.

The capital stock does not seem to react to investment in a generator, but it reduces by about 0.9 percent for a 10 percent diesel tariff increase. This can be the result of a complete or partial depreciation of generators. During the period 2000 to 2015, we find no significant effect of electricity tariff increases on capital stock. Reducing the sample to the period 2000 to 2013, we find a negative effect of about 0.5 percent for a 10 percent electricity tariff increase. We have a preferred interpretation of this finding. As seen in Figure 3, the average generator capacity increases sharply with the strong tariff increases in 2015. This means that firms that have used a generator before started investing in more generators. Reducing the sample to the period 2000 to 2013 excludes this strong investment reaction to the very large electricity tariff increase. Thus, we find that for the smaller tariff increases during 2000–2013, the capital stock decreases (or increases less) for generator using firms compared to similar firms that do not use a generator, probably because generators use expanded mostly at the extensive margin (that is, many firms that we treat as control group in  $t$  started investing in generators at  $t + 1$ , while investment at the intensive margin was low).

The volume of material inputs reacts positively to an investment in a generator (by around 11–13 percent), and negatively to diesel tariff increases: The value decreases by 0.7–1.0 percent for a 10 percent increase. We thus find strong evidence that firms that have relied on generators for electricity input reduce the output volume as well as input volume, that is, production declines. In the period 2000 to 2015, we find that firms that have relied on a generator in the past reduce material input by around 0.8 percent for a 10 percent electricity tariff increase. This may be because even with the increased investment in generators at the intensive margin, substitution possibilities of self-generated versus grid electricity might be limited. For the period 2000 to 2013, where investments in generators took place mostly at the extensive margin, we find no effect of electricity tariffs on material inputs.

#### 4.4 Robustness

The above results are, by and large, robust to different regression specifications and variable definitions (Tables with detailed results are available in the online appendix). None of the parameter estimates change their sign, although some become statistically insignificant at the usual confidence levels. We allow for firms that at some point over the course of 2000 to 2004 owned a generator to experience different growth dynamics by adding a time trend  $T$  interacted with an indicator for generator ownership  $\bar{G}_{isd[2000,2004]}$ . This relaxes the parallel trend assumption between firms that were generator users before drastic tariff adjustments took place, and firms that did not use generators before, by focusing on deviations from the group-specific price-trend. This trend will, of course, pick up the small and constant trends of both diesel and electricity tariffs between 2000 to 2004, and thus some parameter estimates become statistically insignificant, while most results continue to hold. We also use a different time window for the generator reliance indicator of three years instead of five, which was chosen somewhat arbitrarily. Again, some findings are statistically insignificant for this specification, but the general interpretation of results does not change.

### 5 Conclusion

This paper investigates effects of energy price increases on manufacturing firms in Indonesia. Using a rich panel data set and exogenous variation in tariffs, we show that firms reliant on generators to self-produce electricity are affected differently than firms not reliant on generators. Correlations between tariff movements and generator use and capacity suggest that price dynamics greatly influence a firms' decision to invest in a generator.

As expected, diesel tariff increases leave firms that have been relying on a generator in the past

worse off than firms that have not been relying on generator use. They reduce total output, and to a lesser extent value added. Labor demand is adjusted very flexibly, as the number of workers are immediately reduced, as is the volume of material inputs. The capital stock is depreciated to a larger extent as well. It is due to these flexible adjustments that we find no effects on neither labor, nor total factor productivity, and only a comparably small effect on value added. As diesel tariff increases discourage generator use, environmental performance in terms of both energy intensity and emission intensity improves.

The differential effect of electricity tariff increases is theoretically ambiguous, and empirically different from diesel tariff increases. If firms are able to easily substitute self-generated electricity for grid electricity, we would have expected positive effects. Results, however, do not imply positive performance effects, and we thus hypothesize that firms do not want, or cannot easily substitute both types of electricity in the short term. We find a negative effect on value added, labor productivity and to a lesser extent on total factor productivity. Firms do not adjust labor input relative to firms not using a generator, and do not reduce total output. Since generator using firms have a higher cost share also of grid electricity, this translates into lower relative value added and labor productivity. Our interpretation is that generator using firms absorb the price shock to a similar extent than other firms do. Environmental performance indicators are unaffected by electricity price increases. Note, however, that we do not fully capture the dynamics of both the extensive and intensive margins of generator use in our regressions. The stark electricity tariff increase for large customers in 2015 seems to have induced a strong increase in average installed capacity. This implies that large electricity tariff increases might have the unintended effect of worsening the environmental performance of firms by encouraging inefficient generator use.

These findings have implications for countries considering fossil fuel subsidy reforms, or face sharply rising fossil fuel or electricity prices for other reasons. We show that fossil fuel price increases can have severe adverse effects on the manufacturing sector - with important employment outcomes - when it is relying on generator use to a large extent, but that environmental performance improves. Electricity tariff increases do not seem lead to large differential input or output adjustments, but might induce inefficient generator use, with potentially large adverse effects for GHG emissions. Countries that prioritize environmentally friendly economic development would be ill-advised to push firms into using generators. Theoretically, governments have the option to prevent generator use by regulation, by manipulating fossil fuel prices for example via (targeted) GHG emission taxes, or by keeping electricity prices low. In the medium run, electricity supply should be expanded, become more reliable, and less emission intensive.

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# Appendix

## Tables

Table 1: Do tariffs predict prices? OLS regression results

Dependent	<i>log</i> Diesel price		<i>log</i> Gasoline price		<i>log</i> Electr. price	
	(1)	(2)	(3)	(4)	(5)	(6)
<i>log</i> Tariff rate (est. for electricity)	1.108*** (0.007)	1.092*** (0.008)	1.061*** (0.006)	1.044*** (0.008)	1.009*** (0.009)	0.961*** (0.013)
Observations	191,512	182,991	157,916	148,569	264,082	254,398
R-squared	0.922	0.934	0.907	0.927	0.702	0.776
Firm FE		Yes		Yes		Yes

Notes: Standard errors clustered at the district level. \*\*\* p<0.01, \*\* p<0.05, \* p<0.1

Table 2: Summary statistics by generator use, 2000–2015

	Generator user			No generator user		
	Mean	Median	SD	Mean	Median	SD
Capital	61313.48	770.44	3.1e+06	22873.02	178.03	1.4e+06
Number of workers	320.30	92.00	1017.87	130.33	35.00	496.76
Total sales	18460.32	1421.42	1.2e+05	5591.09	295.93	65147.16
Value added	8145.89	522.56	85128.39	2282.07	110.08	29431.39
Value added per worker	19.57	4.88	99.68	9.93	2.73	193.01
Number of generators	32.34	1.00	676.00			
Capacity of generators used KW	1641.61	250.00	7855.13			
Gasoline (1000L)	35.26	0.00	1543.18	15.28	0.10	1319.75
... cost share	0.00	0.00	0.02	0.01	0.00	0.02
Diesel (1000L)	387.61	15.00	5053.69	63.91	0.56	1893.96
... cost share	0.03	0.01	0.07	0.01	0.00	0.04
Electricity (GWh)	3.01	0.14	24.89	0.97	0.01	25.20
Electricity, purchased (GWh)	1.78	0.05	15.94	–	–	–
... cost share	0.04	0.01	0.08	0.03	0.01	0.07
Electricity, self-generated (GWh)	1.23	0.00	17.82			
... variable cost share	0.03	0.00	0.10			
Energy intensity (MJ/value added)	11952.38	4501.43	24458.77	7377.87	2811.72	14779.80
CO2 intensity (kg/value added)	826.40	307.82	1680.67	508.17	191.94	1016.56
Observations	57566			155248		

*Notes:* All monetary values are in millions (2000 IDR). Number and capacity of generators among users are trimmed by year at the 99th percentile. Energy and CO2 intensity trimmed at the 0.5th and 99.5th percentile. Self-generated electricity computed as residual of total electricity consumption and purchased electricity due to data gaps in electricity generation data. Energy intensity of primary energy consumption (electricity and fuels), self-generated electricity included indirectly through fuel consumption. The measure of energy intensity of grid electricity assumes identical efficiency of electricity production (by fuel) between PLN and independent providers. kWh produced by renewable sources is directly converted to MJ. CO2 emissions calculated per fuel input using appropriate conversion factors.

Table 3: Results for total sales and value added

Dependent	<i>log Sales</i>			<i>log Value added</i>		
	Full	Matched		Full	Matched	
	'00-'15 (1)	'00-'15 (2)	'00-'13 (3)	'00-'15 (4)	'00-'15 (5)	'00-'13 (6)
Past generator owner	0.233*** (0.040)	0.126** (0.055)	0.113** (0.052)	0.181*** (0.041)	0.081 (0.054)	0.069 (0.049)
Past generator owner × <i>log diesel tariff</i>	-0.131*** (0.024)	-0.095*** (0.033)	-0.084*** (0.032)	-0.096*** (0.025)	-0.062* (0.032)	-0.055* (0.030)
Past generator owner × <i>log electr. tariff</i>	-0.095*** (0.017)	-0.048** (0.019)	-0.030 (0.020)	-0.089*** (0.017)	-0.053** (0.022)	-0.043* (0.022)
Observations	153,092	78,965	67,626	153,092	78,965	67,626
R-squared	0.904	0.904	0.910	0.888	0.885	0.890
Firm controls	Yes	Yes	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes	Yes	Yes
District-year FE	Yes	Yes	Yes	Yes	Yes	Yes
5-digit-sector-year FE	Yes	Yes	Yes	Yes	Yes	Yes

Notes: Standard errors clustered at the district level. \*\*\* p<0.01, \*\* p<0.05, \* p<0.1.

Table 4: Results for labor and total factor productivity

Dependent	<i>log Valued added/worker</i>			<i>log TFPR</i>		
	Full	Matched		Full	Matched	
	'00-'15 (1)	'00-'15 (2)	'00-'13 (3)	'00-'15 (4)	'00-'15 (5)	'00-'13 (6)
Past generator owner	0.103*** (0.037)	0.055 (0.047)	0.031 (0.043)	0.013** (0.006)	0.006 (0.008)	0.002 (0.007)
Past generator owner × <i>log diesel tariff</i>	-0.055** (0.022)	-0.023 (0.027)	-0.011 (0.026)	-0.008** (0.004)	-0.001 (0.004)	0.001 (0.004)
Past generator owner × <i>log electr. tariff</i>	-0.074*** (0.015)	-0.052*** (0.019)	-0.033* (0.020)	-0.012*** (0.003)	-0.009*** (0.003)	-0.005 (0.003)
Observations	153,092	78,965	67,626	149,206	76,766	65,753
R-squared	0.760	0.753	0.760	0.853	0.848	0.856
Firm controls	Yes	Yes	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes	Yes	Yes
District-year FE	Yes	Yes	Yes	Yes	Yes	Yes
5-digit-sector-year FE	Yes	Yes	Yes	Yes	Yes	Yes

Notes: Standard errors clustered at the district level. \*\*\* p<0.01, \*\* p<0.05, \* p<0.1.

Table 5: Results for energy and CO2 intensity

Dependent	<i>log MJ/value added</i>			<i>log kgCO<sub>2</sub>e/value added</i>		
	Full	Matched		Full	Matched	
	'00-'15 (1)	'00-'15 (2)	'00-'13 (3)	'00-'15 (4)	'00-'15 (5)	'00-'13 (6)
Past generator owner	0.138** (0.061)	0.172** (0.076)	0.162** (0.069)	0.147** (0.061)	0.180** (0.075)	0.171** (0.069)
Past generator owner × <i>log diesel tariff</i>	-0.061* (0.036)	-0.079* (0.047)	-0.073* (0.043)	-0.066* (0.036)	-0.085* (0.046)	-0.079* (0.042)
Past generator owner × <i>log electr. tariff</i>	-0.042* (0.024)	-0.031 (0.030)	-0.021 (0.028)	-0.041* (0.024)	-0.030 (0.029)	-0.020 (0.028)
Observations	149,967	78,311	66,960	149,967	78,311	66,960
R-squared	0.704	0.712	0.726	0.706	0.713	0.727
Firm controls	Yes	Yes	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes	Yes	Yes
District-year FE	Yes	Yes	Yes	Yes	Yes	Yes
5-digit-sector-year FE	Yes	Yes	Yes	Yes	Yes	Yes

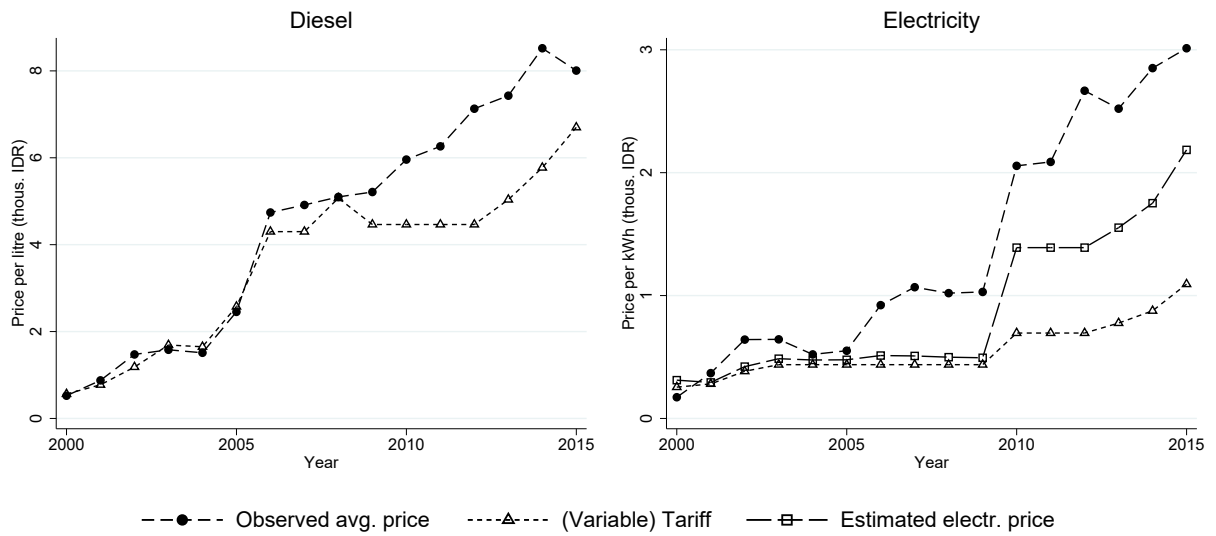
Notes: Standard errors clustered at the district level. \*\*\* p<0.01, \*\* p<0.05, \* p<0.1.

Table 6: Results for labor, capital and material inputs

Dependent	<i>log # of workers</i>		<i>log Capital stock</i>		<i>log Material inputs</i>	
	Matched		Matched		Matched	
	'00-'15 (1)	'00-'13 (2)	'00-'15 (3)	'00-'13 (4)	'00-'15 (5)	'00-'13 (6)
Past generator owner	0.062** (0.029)	0.064** (0.025)	0.085 (0.068)	0.079 (0.060)	0.134** (0.066)	0.110* (0.063)
Past generator owner × <i>log diesel tariff</i>	-0.054*** (0.016)	-0.054*** (0.015)	-0.088** (0.038)	-0.089** (0.036)	-0.097** (0.040)	-0.073* (0.039)
Past generator owner × <i>log electr. tariff</i>	-0.007 (0.012)	-0.012 (0.012)	-0.029 (0.029)	-0.049** (0.024)	-0.077*** (0.025)	-0.038 (0.026)
Observations	78,965	67,626	78,965	67,626	78,965	67,626
R-squared	0.934	0.941	0.868	0.880	0.881	0.890
Firm controls	Yes	Yes	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes	Yes	Yes
District-year FE	Yes	Yes	Yes	Yes	Yes	Yes
5-digit-sector-year FE	Yes	Yes	Yes	Yes	Yes	Yes

Notes: Standard errors clustered at the district level. \*\*\* p<0.01, \*\* p<0.05, \* p<0.1.

# Figures



Variable tariff for electricity. Estimated electricity price per kWh combines monthly load fee (fixed until 2010) and average variable tariff. Estimated price does not include k-factor, and is an average of tariffs I-2, I-3, and I-4

Figure 1: Diesel and electricity prices and tariffs, 2000–2015

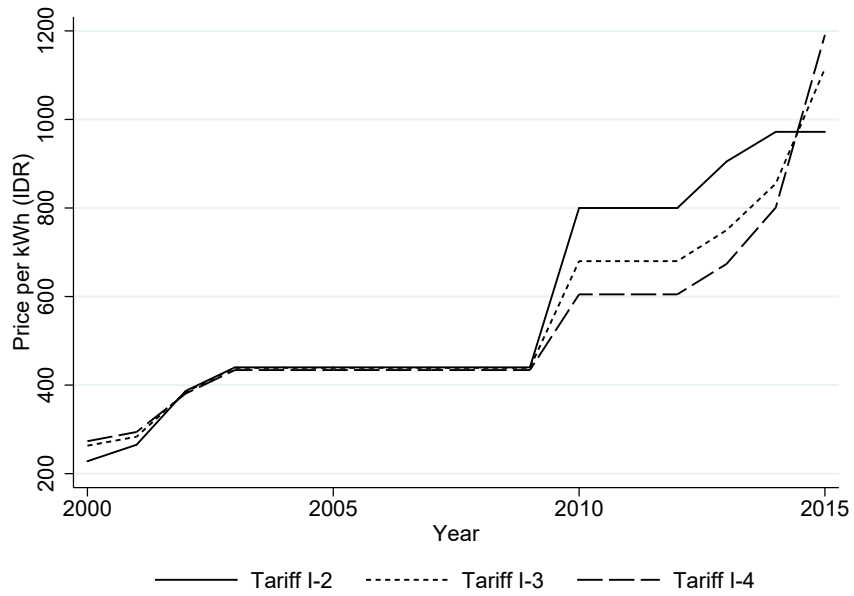


Figure 2: Electricity tariffs by category, 2000–2015

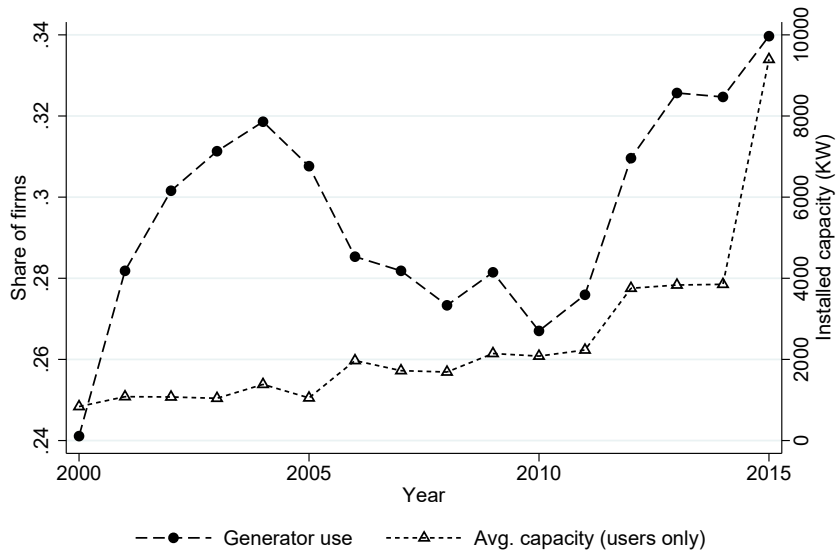


Figure 3: Generator use and capacity, 2000–2015

## Productivity Estimation

We estimate a value-added production function to recover revenue productivity estimates (TFPR). To avoid endogeneity issues due to unobserved productivity shocks, we employ the control function approach of Akerberg et al. (2015), which solves functional dependence problems found in Olley and Pakes (1996) as well as Levinsohn and Petrin (2003). Consider the following Cobb-Douglas production function:

$$y_{it} = \beta_0 + \beta_k k_{it} + \beta_l l_{it} + \omega_{it} + \epsilon_{it} \quad (\text{A1})$$

where  $y_{it}$  is deflated value added of firm  $i$  in year  $t$ ,  $k_{it}$  is the deflated value of capital,  $b_{it}$  the number of blue collar workers and  $w_{it}$  the number of white collar workers.  $\omega_{it}$  is a productivity shock and  $\epsilon_{it}$  an iid error term. All variables are expressed in logs.

We do not observe  $\omega_{it}$ , but it is known by the firm and likely affects production as well as input choices. The control function approach models firm behaviour to infer productivity shocks from observables. Akerberg et al. (2015) rely on following assumptions:

- (1) The information set  $I_{it}$  of the firm includes current but not future productivity shocks and  $E[\epsilon_{it}|I_{it}] = 0$ .
- (2) The distribution of productivity shocks follows a first-order Markov chain:  $p(\omega_{it+1}|I_{it}) = p(\omega_{it+1}|\omega_{it})$ .
- (3) Accumulation of capital:  $k_{it} = K(k_{it-1}, i_{it-1})$ , with investment  $i$  chosen in  $t - 1$ . Labour inputs are allowed to be chosen at  $t$ ,  $t - 1$  or  $t - b$ ,  $0 < b < 1$ .
- (4) Intermediate input demand:  $m_{it} = M(k_{it}, l_{it}, \omega_{it})$ .
- (5)  $M(k_i, l_{it}, \omega_{it})$  is strictly increasing in  $\omega_{it}$ : Productivity gains lead to higher intermediate input demand.

Inverting input-demand function gives  $\omega_{it} = M^{-1}(k_{it}, l_{it}, m_{it})$ . Plugging into equation (A1):

$$\begin{aligned} y_{it} &= \beta_0 + \beta_k k_{it} + \beta_l l_{it} + M^{-1}(k_{it}, l_{it}, m_{it}) + \epsilon_{it} \\ &= \Phi_t(k_{it}, l_{it}, m_{it}) + \epsilon_{it} \end{aligned} \quad (\text{A2})$$

Equation A2 is estimated non-parametrically using GMM estimation and the respective moment condition. It produces an estimate of  $\Phi_t$ , which is used in the second stage estimation. Using assumptions (1) and (2),  $\omega_{it}$  is decomposed into the conditional expectation plus the innovation

term of interest ( $\xi_{it}$ ):

$$\omega_{it} = E[\omega_{it}|I_{it-1}] + \xi_{it} = E[\omega_{it}|\omega_{it-1}] + \xi_{it} = g(\omega_{it-1}) + \xi_{it}$$

Substituting this expression into the production function then gives:

$$\begin{aligned} y_{it} = & \beta_0 + \beta_k k_{it} + \beta_l l_{it} \\ & + g(\Phi_{t-1}(k_{it-1}, l_{it-1}, m_{it-1}) - \beta_0 - \beta_k k_{it-1} - \beta_l l_{it-1}) + \xi_{it} + \epsilon_{it} \end{aligned} \tag{A3}$$

which is again estimated using GMM with the respective moment condition. Predicting the residual after estimation produces the estimate of TFPR.

We estimate a translog production function relying on the Stata command *prodest* (Rovigatti and Mollisi, 2018) using 200 bootstrap repetitions, and split the sample according to three-digit industry identifiers. Values of value added, material and capital inputs are deflated by a nation-wide output/material/capital industry-price index. For 2006, the capital stock variable is missing. We infer the value from 2007 data, adding depreciation and subtracting sales.