Too Much Energy
The Perverse Effect of Low Fuel Prices[*][†]

PRELIMINARY - PLEASE DO NOT QUOTE OR CIRCULATE

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Abstract

Based on large nationally representative samples of manufacturing plants in two of the largest developing countries (Indonesia and Mexico), this paper provides novel evidence that an increase in energy prices does not necessarily worsen economic performance. We find that an increase in fuel prices results in higher productivity and profits by providing incentives to invest in more efficient and productive capital equipment. Our estimates imply that a ten percent increase in fuel prices would lead to a 3% increase in total factor productivity for Indonesia and 1.2% for Mexico. We conclude that policies based on carbon taxes or subsidy reforms can not only be used to achieve environmental goals, but also to improve economic performance.

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1 Introduction

Curbing fossil fuel consumption is essential to reduce the process of global warming and keeping it within levels that may not dramatically disrupt the functioning of societies (Intergovernmental Panel on Climate Change, 2018). Yet, governments are reluctant to take significant measures to reduce emissions, including decisive taxes on carbon. This resistance is partly due to the concern that an increase in the price of energy could be harmful to domestic producers, as it would increase the cost of a key input to production. The argument is particularly salient in industrialising countries where in fact fuel consumption is often subsidized.[1]

This paper provides novel evidence that an increase in energy prices does not necessarily worsen economic performance in developing countries. In fact, we find that an increase in fuel prices results in higher productivity and profits by providing incentives to invest in more efficient and productive capital equipment. We base the analysis on large nationally representative samples of manufacturing plants in two of the largest developing countries (Indonesia and Mexico). In this way, threats to external validity which typically affects single country empirical analyses are less of a concern in our framework. Our approach also implies that the results are not specific to a particular setting or identification strategy. To address the endogeneity of energy prices and plant-level outcomes, we construct instrumental variables based on geographical characteristics for Indonesia and on the institutional system for Mexico. Despite wide differences between the two economies and the instrumental variables adopted, we find a robust pattern linking fuel prices and economic performance. This result does not apply to the other main energy source - electricity - whose price increase have a negative or non significant impact on firms' performance, in line with previous studies (Abeberese, 2017; Marin and Vona, 2017). Our estimates imply that a ten percent increase in fuel prices would lead to a 3% increase in total factor productivity for Indonesia and 1.2% for Mexico. We conclude that policies based on carbon taxes or subsidy reforms can not only be used to achieve environmental goals, but also to improve economic performance.

To the best of our knowledge, this is the first paper providing systematic evidence on higher factor costs leading to a more productive use of resources. In the energy literature, such a possibility is known as the strong version of the Porter Hypothesis, which was theorized by Porter and van der Linde (1995). In its strong version, the Porter Hypothesis has not received empirical support to date.[2]

The crucial innovation of this paper is testing for the impact of energy price variations separately for electricity and fuels, the two main types of energy used by manufacturing firms. Most of the literature on energy and plants' performance has focused on electricity (e.g. Abeberese, 2017; Marin and Vona, 2017; Allcott, Collard-Wexler, and O'Connell,

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[1] Coady, et al. (2015) estimate that energy subsidies would account for between 13% and 18% of GDP in Developing and Emerging Asia, the Middle East, North Africa, and Pakistan (MENAP), and the Commonwealth of Independent States (CIS).

[2] Cantore et al. (2016) show that the trade-off between higher energy prices and performance might be softened by the positive relation between energy efficiency and productivity, but they do not study how energy prices affect technological choice.

2016).[3] However, distinguishing between electricity and fuels is important because they power capital equipment of different types. A case in point is the boiler, which is used to produce heat in virtually all manufacturing industries: fuel-powered boilers tend to be older, less energy-efficient and less productive than electricity-powered ones (Malek, 2005). Hence, variations in relative prices could shape incentives to adopt different vintages of capital equipment. In line with this hypothesis, we find that higher fuel prices trigger scrapping of fuel-powered machinery and purchasing of electricity-powered equipment, increase electricity consumption per unit of capital and boosts overall energy efficiency. Moreover, the data in both countries show that electricity-intensive plants are more productive and energy-efficient than their fuel-intensive counterparts (controlling for narrowly defined sectors of activity).[4] Based on such evidence, our working hypothesis is that new technology tends to be embodied in electric vintages of capital, which are more productive than their fuel-powered predecessors. Thus, the switch towards electric machinery induced by fuel price hikes is a form of technological upgrading, which increases the firm's productivity. Further support for our reading of the data comes from the fact that the positive impact of fuel prices on performance is muted for foreign plants. A large literature suggests that foreign firms are more likely to operate frontier technologies, hence leaving less need for technological in response to fuel price increase.[5]

From a theoretical standpoint, with no market imperfections and profit-maximizing producers, an increase in factor cost must necessarily lead to worse performance: if profitable opportunities existed before the price increase, rational producers would already be exploiting them.[6] However, a growing literature finds evidence of market imperfections and bounded rationality even in advanced economies (McKinsey & Co., 2009; Anderson and Newell, 2004; DeCanio and Watkins, 1998; Poterba and Summers,1991; DeCanio, 1993). Further, a number of case studies suggest that investment in technology undertaken with the primary objective of increasing energy-efficiency often provide surprisingly high productivity gains.[7] Findings in Ryan (2018) and Bloom et al. (2013)

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[3] Rentschler and Kornejew (2017) is among the few studies studying the impact of a variety of energy sources on performance. However, one important difference between Rentschler and Kornejew (2017) and our paper is that they use cross-sections of small and micro Indonesian manufacturing firms. Instead, this paper focuses on panels of medium and large plants.

[4] Case studies evidence are consistent with our results. Electric heating technologies are considered to be not only more energy-efficient than fuel-powered ones, but also able to generate non-energy productivity gains such as better product quality, process flexibility, speed and reliability. See for example EPRI (2007) and references therein.

[5] Preliminary findings from our analysis show that foreign plants are indeed more electricity-intensive than their counterparts in comparable sectors of activity.

[6] With market imperfections it is theoretically possible to have a positive link between factor prices and productivity. For instance, within a standard model of directed technical change, Acemoglu (2010) shows that market power in the technology-producing sector can lead firms to chose not the profit-maximizing technology. In that model, the increase in price of a factor can induce adoption of a technology which "saves" on that factor, ultimately resulting in a increase of productivity. The theoretical model in Acemoglu (2010) is consistent with empirical evidence in Popp (2002), where higher energy prices lead to development of energy-saving technology.

[7] Pye and McKane (2000) document how energy efficiency projects increase shareholder value. Worrell et al. (2003) find that the majority of the case studies in manufacturing sectors across six OECD countries

suggest that the frictions responsible for sub-optimal investment decisions might be even more severe in less advanced countries. The incentives to gather and process information about energy-efficient technological opportunities might be particularly low in Indonesia and Mexico, where heavily subsidized prices result in energy-efficiency being not a major concern for the average producer. Our finding that the positive impact of fuel prices on performance is muted for foreign plants is consistent with the market frictions and bounded rationality hypothesis, as information frictions and deviation from profit-maximizing behavior are likely to be more limited for these firms.

The rest of the paper is organized as follows. Section 2 describes data; Section 3 the identification strategy; Section 4 provides the results, and Section 5 concludes.

2 Data

Before turning to the data, we briefly discuss the reasons underlying the choice of using Indonesia and Mexico to study the impact on fuel prices on technological choice and firms' performance. First, they are two of the largest emerging countries, which together account for 2.6% of world's CO2 emissions.[8] A significant part of the emissions is due to fuel consumption, which is sustained by long-standing policies of subsidized fuel prices in both countries, including for industrial users. These subsidies translate into some of the lowest fuel prices among a large sample of countries for which this data is available (Figure 1).[9] The low prices have contributed to relatively high consumption of fossil fuel by domestic industries in both countries. Fuels account for roughly 65% of total energy consumption in the average manufacturing plant in Indonesia, 63% in Mexico, but only 40% in France (Marin and Vona, 2017), where fuel prices are considerably higher.

In addition the geography and institutional features of the countries help identify exogenous sources of variation of energy prices, which are key to our identification strategy. As explained below, in Indonesia local characteristics affect the propagation of national energy price changes at the local level; in Mexico the energy prices are set at the state level, which along with industry and plant characteristics allows us to isolate exogenous components of energy price changes. Indonesia and Mexico also provide access to detailed manufacturing plant-level datasets available in developing countries including information on quantity and expenditure of energy consumed by energy source, investment by type of asset and other key information on production that can be used to estimate productivity. That is unusual especially for non high income economies, for which the scarcity of granular data has constrained the evidence on the impact of environmental policies on firms' performance.

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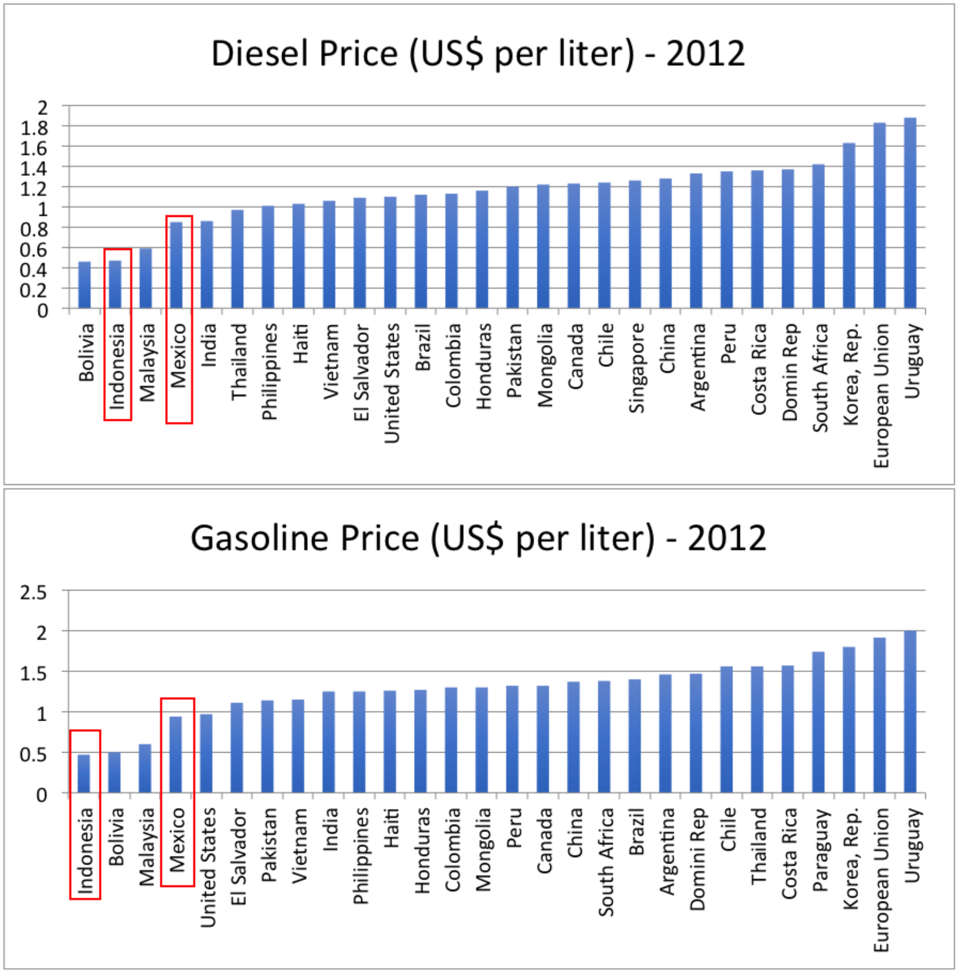
exhibited non-energy benefits of equal or greater size than the energy savings.

[8] The figure refer to 2014 according to World Bank Data on emissions.

[9] In Indonesia the subsidy has been largely phased out in the public budget at the end of 2014, but energy prices continue to be implicitly subsidized by the state owned monopolists of electricity production and distribution and of fuels distribution, thus also generating concerns for their economic sustainability.

Figure 1: International comparison of energy prices. Source: Beylis and Cunha (2017)



2.1 Indonesian Data

Plant level data are taken from the Indonesian survey of manufacturing plants with at least 20 employees (Statistik Industri) administered by the Indonesian statistical office (BPS). The coverage of the survey is extensive; in fact it becomes an actual census in 1996 and 2006 and it is very close to a census in the remaining years, hence ensuring high representativeness even at the provincial level. Plants are grouped into 5 digits sectors following the definition Klasifikasi Baku Lapangan Usaha Indonesia (KBLI), a classification mostly compatible with ISIC Rev.3. The KBLI classification has been adjusted to be consistent over the whole sample, ranging from 1990 to 2015. The plant level data provide information on several variables such as output, capital stock, employment, materials and energy usage by type.

One of the key challenges of the Statistik Industri data is the lack of complete series of capital stock. Earlier studies tried to re-construct capital stock series applying the perpetual inventory method (PIM) to the first year of capital stock data reported by the plant (Amiti and Konings, 2007; Javorcik and Poelhekke, 2017). However this imputation method crucially relies on the capital value self-reported by the plant the first year this data is available, which is not necessarily accurate.[10] One potential advantage of using PIM is that purchase and sales data might be more accurate relative to self-reported value of the stock, requiring an appropriate calculation of market values and depreciations. However, PIM needs to rely on measures of capital depreciation, which are difficult to accurately estimate. To mitigate such tradeoff, we have adopted a hybrid strategy. We first clean the self-reported adopting an algorithm which keeps only observations that fulfill a battery of tests.[11] Then, we apply the PIM only to fill the gaps between the missing observations and reapply the battery of tests to ensure consistency of the series. Output price deflators are constructed by matching wholesale BPS price indexes available at the 5 digits level IHPB classification (Indeks Harga Perdagangan Besar) with KBLI. Moreover, we are able to obtain different capital deflators depending on the type of asset. We distinguish general price deflators from machinery and equipment, vehicles, and buildings. For all deflators, 2010 is used as a base year.

2.2 Mexican Data

In the case of Mexico, we use plant-level data from the Annual Manufacturing Industry Survey (EAIM in Spanish), which is conducted by the National Institute of Statistics and Geography (INEGI). This survey provides yearly statistically representative information at the national and NAICS-6-digits level for the 2009-2015 period. EAIM information is mainly used to calculate performance variables (TFPR, TFPQ, Value-added per worker, profits and profitability), as well as energy intensity, energy efficiency, and machine turnover. We also use information from the Monthly Manufacturing Industry Survey (EMIM), from INEGI which includes the same sample of manufacturing establishments as the annual survey in order to analyze the monthly production of each firm and to construct the energy prices that each establishment faces in an adequate manner. As 2009 is the initial year of analysis, we also use information from the 2009 Economic Census on the share of foreign capital that each firm has.

The sources of information for energy prices are first, INEGI, that publishes monthly production volumes for coal and coke. Information regarding monthly gas and diesel prices is obtained from the Ministry of Energy, which provides monthly prices as well as energy consumption by industry. Finally, for electricity, we obtained prices from the Energy Federal Commission (CFE) on volumes, values, and number of users for the different electricity tariffs applied in Mexico.

One important limitation of our analysis is that, though we have detailed information at the establishment level to construct performance information, the data regarding energy consumption tends to be highly concentrated and in terms of values. Therefore,

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[10] In particular, there is no a priori reason to believe that the quality of the self-reported capital stock the first year is necessarily better than the value in other years.

[11] The procedure is described in the appendix.

to construct the series of prices that each firm faces, we needed analysis and information from different sources.

To construct electricity prices, as the information we have is the total expenditure in electricity at the establishment level, we obtained data on the number of users, total sales and the volume of sales from the Federal Electricity Commission (CFE) at the state level for the period of analysis. We also obtained the tariff schemes from the CFE, which yields 32 tariffs with regional and seasonal differences. Of them, we selected four tariffs that apply to medium and large companies in the manufacturing sector, which depend on consumption levels, duration, and costs (fixed and variable). Using the information on sales and consumption, we calculated average tariffs and average bills paid in order to generate bill ranges for each state to assign a tariff to each establishment, based on its expenditure on electricity. We assigned four different electricity tariffs (two for medium-sized companies and two for large companies). Once we defined the tariff-level that each company faces, we calculated a weighted price using the monthly share of production in the initial period as weight.

In the case of fuels, due to the lack of detailed information to construct the prices series by type of fuel used, we analyzed the manufacturing industry fuels consumption and we were able to identify four main fuels that account for more than 85% of total other fuels consumption in this industry: coal, petroleum coke, diesel, and natural gas. Then, we obtained from the Ministry of Energy the share that each of these four main fuels represented of total consumption at each NAICS 4-digits sector for the initial year. We were able to obtain data from the Ministry of Energy and INEGI on national monthly prices and in the case of natural gas, at the regional level. Thus, we calculated a monthly composite index at the NAICS-4 digits sector weighting these prices by sectoral consumption. Once we had a monthly price that each firm would face according to the consumption pattern of the sector in which it operates, we calculated the annual price that the firm faced, once again assuming that energy consumption correlates perfectly with production over the year.

2.3 Productivity Measures

We estimate two widely used measures of productivity, revenue-total factor productivity (TFPR) and physical-total factor productivity (TFPQ). For each plant f and year t, TFPR is computed following the approach in Aw et al. (2000):

$$ln(TFPR)_{ft} = ln(VA_{ft}) - ln(\overline{VA}) - \left[\frac{1}{2}\sum_{j=1}^{k}(S_{jft} + \overline{S}_j)(ln(X_{jft}) - ln\overline{X}_j)\right]$$

In the previous equation, VA_{ft} is the value added of the plant, S_{fjt} its revenue share for input j and X_{jft} quantity used of the same input. As it is standard, we consider capital and labor as factors of production. Upper bars represent averages within each two digits sector and year. While it would have been possible to estimate TFPR following the methodology in Olley and Pakes (1996), we prefer to use a non-parametric method in order to mitigate identification concerns due to estimation process and the choice of the functional form.

An important concern is that TFPR might be a biased indicator of technical efficiency because being based on revenue and so it might capture changes in prices and markups. Therefore, we also estimate TFPQ at the product-level using a trans-log production function, as in De Loecker et al. (2016). Using this methodology allows to purge the productivity measures from two important sources of bias: input price-bias and input allocation-bias.[12]

3 Identification Strategy

A key advantage of our manufacturing data is the detailed breakdown of energy use, allowing to measure how plants react to variation in the price of different energy sources separately. However, simply regressing outcomes on prices might result in biased estimates due to the potential endogeneity of energy prices. For instance, demand shocks could generate an increase in economic activity driving up both energy prices and plant-level investment. Reverse causality could also be an issue, as technology shocks or local infrastructure development might drive down the cost of energy and boost plants' performance. To mitigate these issues, we include two-digits sector-year dummies accounting for changes in market conditions and development in sector-specific technologies. We also include region-time trends to control for differences in local development and changes in infrastructures.[13] However time-varying unobserved variables at the plant level would not be controlled for by the inclusion of plants' fixed effects. That would be the case for example if hiring a new manager would enable to improve plants' performance and negotiate lower energy prices with local suppliers, or optimise production to maximise energy consumption during non peak hours. Similarly hiring a politically connected manager could result in larger profits and preferential energy rates. Therefore, to overcome the issue we obtain instrumental variables for plant-level energy prices. To facilitate the reading we postpone the detailed descriptions of the instrumental variables after the discussion of our identification strategy.

With our instrumental variables for plant level energy prices, we estimate the following system of equations separately on the Indonesian and Mexican samples:

$$\hat{P}^{i}_{ft} = \alpha_0 + \alpha_1 inst^{i}_{ft} + D_{st} + trend_r + u_f + \eta_{ft} \tag{1}$$

$$Y_{ft} = \beta_0 + \beta_1 \hat{P}^{fuel}_{ft} + \beta_2 \hat{P}^{elec}_{ft} + D_{st} + trend_r + u_f + \varepsilon_{ft} \tag{2}$$

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[12] Details on the methodology can be found in De Loecker et al. (2016)

[13] Regions correspond to the 6 main islands of the archipelago for Indonesia (Sumatra, Java, Bali & Nusa Tenggara, Kalimantan, Sulawesi, and Maluku & Papua), and 32 states for Mexico

In (A1), $i = \{fuel, elec\}$. In both equations, hats emphasise that average energy prices are obtained by dividing energy expenditure by energy consumption, which we converted in kWh equivalents.[14] Since our focus is on the distinction between fossil fuels and electricity, we categorise each energy type used by the plants into one of the two groups. This strategy eases the interpretation of the results and mitigates potential correlation across prices for different fuel sources which might inflate the standard errors of the individual fuel coefficients. For Indonesia, electricity includes both that purchased from the State-Onwed national monopolistic provider Perusahan Listrik Negara (PLN) and that purchased by foreign providers. For Mexico, the only available electricity source is included. The fossil fuel sources considered are different for the two countries. Indonesia includes diesel, gasoline and lubricants, which together with electricity account for roughly 80% of all energy sources.[15] Mexico includes diesel, coal, natural gas and coke. These sources account for 85% of fossil fuel consumption in the Mexican dataset. For both samples, within each of the two electricity and fuel categories, we compute plant-level quantity shares (in kWh equivalents) in order to capture the relative importance of each source.[16] To avoid potential endogeneity of time-varying proportions, for each plant we compute shares in their first year of observation and then drop it from the analysis.[17]

In (A1), $inst^i_{pt}$ is the respective instrument for energy prices. The second stage (2) relates energy prices to plant-level outcome, Y_{ft}. Year and sector-year dummies are denoted by D_{st}, while $trend_r$ is a region-time trend. The term u_f is the plant fixed effect. After controlling for economy-wide and sector-specific market factors, as well as for plants' unobserved characteristics, identification of our coefficients of interest is obtained by comparing plants' outcomes over time in plants facing different changes in energy prices.

3.1 Instrumental Variables for Indonesia

In Indonesia the prices of the main energy sources are set by the Ministry of Energy and Mineral Resources in accordance with the State Owned national distribution monopolists PLN and Pertamina.[18] As such, they are supposedly homogenous across the country. However, the highly variegated geography characterizing Indonesia results in substantial

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[14] We used the following standard conversion factors: 1 litre of Diesel corresponds to 10 kWh; gasoline: 9.1 kWh; lubricants: 11 kWh; 1 kg of coal is equivalent to 8.1 kWh; 1 m^3 of natural gas is equal to 11.7 kWh, and 1 kg of coke is equal to 8.8 kWh.

[15] The Indonesian survey asks manufacturers about expenditures and quantities of PLN and non PLN electricity, gasoline, diesel, kerosene, coal, gas, LPG, lubricant, oil diesel, oil burn, charcoal, firewood, coke plus a category labelled "other fuels". However, exception made for PLN, non-PLN electricity, diesel, gasoline and lubricants, all other sources have been included in "other fuels" in some years. Therefore, to minimize noise, we limit the analysis to the energy sources that have been separately identified in every year in the sample.

[16] Results are robust to alternative weighting schemes.

[17] A similar strategy can be found in Marin and Vona (2017), which instead use the actual time-varying shares for the endogenous regressor. We also experiment with this method and find very similar results with the two methods.

[18] PLN for electricity and Pertamina for diesel, gasoline, lubricants and gas.

heterogeneity in distribution costs across different provinces, scattered across seven major geographical units, consisting of major island or groups of Islands.[19] In Indonesia, the large variation in energy distribution costs is well documented (IEA, 2015; Inchauste and Victor, 2017) and it is especially acute for fossil fuels. Differences in accessibility result in energy being persistently more costly to supply in some areas.[20] However, events such as the closure of a road, disruption in naval shipment or technical failure of a supplier's transportation equipment add substantial randomness to the propagation of nationally mandated prices energy prices.[21] In remote regions such as Papua and North Kalimantan, where fuel can only be transported by aircrafts and sea vessels, the price of fuel is extremely sensitive to disruptions of the transportation network.[22]

A valid instrument must affect plants' performance only through its impact on plant-level prices. Therefore, our strategy is exploiting our data to isolate the geographical markup on energy prices due to shocks to the cost of distributing energy to a particular province. To do so, we first use plant-level information on values and quantity of energy consumed by energy type to compute the unit price paid by plants for each source of energy, which corresponds to its average unit cost. Then, for each plant we compute the average price paid by other plants populating that province in each year. Finally, we divide this average price by the country-wide average price in order to minimize the potential correlation of plant-level outcomes with macroeconomic factors affecting energy prices. Such instrument can be interpreted as a proxy for the (time varying) cost of distributing energy in a particular province and thus it is correlated with plant-level energy prices. At the same time, excluding the plant in question from the computation of the average prices, the instrument is also less likely to be correlated with plant level outcomes. A further concern may be that the instrument may also captures local-level dynamics such as fluctuations in demand, production or infrastructure development, thus invalidating the exclusion restrictions. In order to address such concerns, we also control for province-level real GDP.

3.2 Instrumental Variables for Mexico

To construct our instrumental variables for Mexico, we rely on the institutional characteristics of price setting. In the case of electricity prices, the tariff scheme includes 32 tariffs with regional and seasonal differences, and in this case, tariffs are determined by infrastructure availability and voltage. Therefore, considering these regional and seasonal characteristics of prices, we construct our instrument as the average price index

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[19] While Idonesia now is divided into 33 provinces, we use the administrative division of provinces at the beginning of our period of analysis, when Indonesia was split into 27 provinces.

[20] For instance, in their cross-sectional analysis, Rentschler and Kornejew (2017) exploit such variation to construct their instrument for energy prices. But in our dynamic framework, we cannot solely rely on geographical differences, which are clearly time-invariant.

[21] In some cases, variation is induced by policy. For instance, missing high-voltage electricity transmission have prompted authorities to approve higher tariffs in remote areas to unlock local small-scale supply from independent utilities (IEA, 2014).

[22] In 2016, the Government of Indonesia implemented a program named "One-price Fuel Policy", aimed at equalizing the cost of fossil fuel across the archipelago.

for the same sector, tariff level, and state (excluding the firm analyzed in each case). Due to the characteristics of prices, as the firm is not considered in the calculation, this price should be exogenous to the plant.

In the case of fossil fuels, a similar rationale operates. Prices for fuels have been heavily regulated. From 2006 to 2014, gasoline and diesel in Mexico were below market prices and the control mechanism used for this was a Special Tax for Products and Services (IEPS in Spanish). This tax could be positive (when market references were below local prices) or negative (when market references were above local prices). During this period, the negative tax worked as a subsidy, recognizing the price gap to the national oil company. Also, prices at the border with the United States of America followed a similar regime, although trying to standardize them with those in the U.S. to maintain local industry and maquila competitiveness. Fossil Fuel Subsidies were the business as usual scenario for Mexico, with controls and nationwide prices for transportation fuels and LP Gas, but a gradual phase-down was put in motion with the approval of the Energy Reform, in 2014.

For the natural gas prices, since the creation of the Energy Regulatory Commission (CRE), in 1993, they have been set according to international references located in the Gulf of Mexico, and adjusted through a net-back mechanism to balance the availability and cost of opportunity between domestic production in the southeastern region in Mexico and the imported gas from the U.S. Later, with the development in Mexico of liquefied natural gas (LNG) facilities to import this fuel from other regions, price references from Gulf Coast and the West Coast of the United States have also been used. Currently, the price structure for this fuel is regulated by the CRE and takes into consideration the costs of transportation, distribution (location of the gas pipelines and connectivity), additional services, and other regional factors.

Also, price definitions fall now under the jurisdiction of the Energy Regulatory Commission (CRE), in coordination with the Federal Economic Competition Commission (COFECE). They are mandated to determine prices and price methodologies according to market conditions, opportunity costs of foreign trade of fuels and competitiveness conditions provided by international markets. The government will set maximum prices for fuels, but they will tend to disappear as market conditions settle, required logistic infrastructure is developed and more participants join in. Also, the government could determine focalized incentives to maintain competitive prices in rural and marginal urban areas. The reform is in its final stages of implementation, LP Gas prices were released in 2017 and gasoline price controls were supposed to be gradually removed between 2017 and 2018. Though as a result of the energy reform it is expected that fuel prices will be more competitive and new logistics infrastructure will be created, regional prices will be still established, which are associated to the local infrastructure, trade capabilities and opportunity costs. This might not always be reflected in cheaper prices because of existing bottlenecks and distribution costs. All these institutional regional characteristics allow us to construct an exogenous instrument that varies according to sector and state for fossil fuels in a similar way to the one we constructed for electricity.[23]

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[23] We also tested alternative instruments analyzing the average index within tariff and state but ex-

4 Results

4.1 First Stage

Table A1 in the appendix presents the first stage regressions. For both countries, the instruments precisely predict plant-level energy prices. In Indonesia, the IV for electricity has also a small but positive impact on plant-level fuel prices. For Mexico, the IV for electricity price has instead a negative impact on fuel prices. The IV for fuel prices, our main variable of interest, predicts plant-level fuel prices but not electricity prices.

4.2 Energy Prices and Plants' Performance

Table 1 presents the impact of energy prices on plants' performance.[24] In both countries, fuel prices have a positive impact on all performance measures considered.[25] A ten percent increase in fuel prices boosts TFPR by 3% and 1.2% in Indonesia and Mexico, respectively. A positive effect is also found for labor productivity (3% and 2.5%), and profit margins (2% and 0.4%). The results for electricity are broadly in line with the existing evidence, which finds a negative impact of electricity prices on firms' performance (Abeberese, 2017; Marin and Vona, 2017; Allcott, Collard-Wexler, and O'Connell, 2016). For Mexico, we find that a ten percent increase in electricity prices lowers TFPR (-2.8%), labor productivity (-2.4%) and profit margins (-0.025%). The sign of the coefficients on electricity prices is negative but never significant for the Indonesian sample.

We thus uncover an asymmetry of impact of prices for different sources of energy: electricity price hikes are detrimental for plants' performance, while fuel prices have a positive effect. To explain our result, we put forward the following hypothesis. Old technology is embodied in capital vintages that are more likely to be powered by fuel, while new technology tends to be embodied in electric capital vintages. A technology that is especially relevant in our framework is the heating system, used pervasively in manufacturing to shape components or transform materials. For instance, old generations of boilers are powered by coal or gasoline, while new generations of the same technology are electric (Malek, 2005).[26] Thus, an increase in fuel prices induces managers to scrap old fuel-powered machinery and purchase new electric equipment. Case studies evidence suggest that electric heating technologies are not only more energy-efficient, but also able to generate non-energy productivity gains, such as better product quality, process flexibility, speed and reliability (EPRI, 2007). Thus, since electric machinery is more

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cluding own sector, and average index within tariff and sector but excluding own state. Each of these composite instruments is weighted by constant initial production in the first year, and alternatively, current production. The results are robust to these different specifications.

[24] To maximise comparability, the results in Table 1 are obtained with a restricted sample for Indonesia which matches the time span of the Mexican data, running from 2009 to 2015. Very similar results are obtained with the full Indonesian sample, starting in 1991.

[25] Results for TFPQ are under construction, but preliminary evidence from Mexico is fully consistent with the current results.

[26] Another striking example is the arc furnace, an electric heating system which came to replace the blast furnace powered by fuel.

productive and energy-efficient, the negative effect of the fuel price increases is compensated by the positive effect on technological upgrading, with a potentially positive net effect on performance. It follows that electricity price hikes do not trigger substitution, because electric technologies are less likely to be outdated. Hence, the negative impact on performance. Clearly, a firm might use not the latest vintage of an electric piece of machinery and so when the price of electricity increases, managers might have an incentive to upgrade towards a more efficient vintage. That could deliver marginal improvements, partially compensating the negative impact of the price increase (the higher cost of running the equipment) and resulting in a net zero effect, as we find for Indonesia.

Table 1: Impact of energy prices on performance.

	(1)	(2)	(3)	(4)	(5)	(6)
	ln(TFPR)		ln(VA/ worker)		profits/ VA	
	IDN	MEX	IDN	MEX	IDN	MEX
ln(Price fuels)	0.311***	0.124***	0.298***	0.244***	0.201***	0.0363***
	(0.087)	(0.0145)	(0.068)	(0.0330)	(0.067)	(0.00611)
ln(Price electricity)	-0.007	-0.285***	-0.030	-0.245***	-0.046	-0.0253**
	(0.051)	(0.0324)	(0.043)	(0.0562)	(0.028)	(0.0118)
Plant, sector-year fixed effects; region-time trends	Yes	Yes	Yes	Yes	Yes	Yes
Observations	76610	37413	97780	40826	97780	42136
Plants	15076	6449	17533	7467	17533	7551
Underidentification	730	295	978	303	978	313
Weak identification	533	130	851	137	851	142

4.3 Energy Prices and Technology Upgrading

If our hypothesis that fuel price hikes trigger technology upgrading towards electric machinery is correct, we should observe three phenomena: i) when fuel prices increase, plants should invest in electric machinery; ii) electricity-intensive plants should perform better than other comparable plants, and iii) the positive impact of fuel prices should be muted in plants more likely to be on the technological frontier. This section tests these predictions.

Although our data provide information on sales and purchases of capital by type of asset, we cannot observe whether transactions on equipment refer to machinery powered by fuel or electricity. However, using energy consumption data we can infer potential changes in capital composition by looking at the energy content of plants' capital stock. Column 1 of Table 2 shows that an increase in fuel prices boosts machinery turnover.[27] Table A2 of the appendix displays the result of a placebo experiment, showing that fuel prices have a marginal effect on vehicles' turnover but no impact on turnover of land.

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[27] Given the lumpiness of investment data at the plant level, we smooth the series by constructing a measure of machinery turnover (sales + purchase of machinery and equipment), which allows us to use OLS.

This result reassures us that the effects of energy prices on machinery turnover shown in Table 2 are not an artefact of the data. At the same time, electricity prices tend to have a negative impact on turnover of vehicles in both countries, and also for land in Mexico. One potential explanation is that an increase in cost of electricity triggers a negative income effect.

Columns 3 and 4 show that an increase in fuel prices result in an increase in the electricity content of capital, but an increase in electricity prices lowers, rather than increasing the fuel intensity of capital (columns 5 and 6). This is consistent with our hypothesis that fuel price hikes induce substitution towards electric machinery.[28] The own price elasticities are negative as expected, except for Mexico in column 6, where the impact of fuel prices on the fuel-intensity of capital is very imprecisely estimated.We also find that a ten percent increase in fuel prices results in a 3% and 4% increase in capital productivity for Indonesia and Mexico, respectively (columns 7 and 8). On the other hand, electricity prices tend to affect negatively the productivity of capital. In columns 9 and 10, we find that higher fuel prices increase overall energy efficiency, computed as value added on total energy expenditures. The impact of electricity prices on energy efficiency differs in the two countries: small but negative for Indonesia and large and positive for Mexico. One potential explanation for the asymmetry are differences in diffusion rates across the two countries. Learning to use a technology takes time, so if adoption of electric technologies is more recent in Indonesia, managers might be unable to adjust operations as to absorb the increase in prices.

Table 2: Machine turnover, electricity/fuel intensity, productivity of capital and energy efficiency

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	ln(purchase+sales) of machinery		ln(qElec/K)		ln(qFuel/K)		ln(VA/K)		ln(VA/ENERGY)	
	IDN	MEX	IDN	MEX	IDN	MEX	IDN	MEX	IDN	MEX
ln(Pricefuels)	0.234**	0.356*	0.181**	0.226**	-0.377***	0.00453	0.295***	0.412***	0.216**	0.222***
	(0.110)	(0.212)	(0.077)	(0.0981)	(0.083)	(0.416)	(0.051)	(0.0705)	(0.106)	(0.0359)
ln(Priceelectricity)	-0.330***	-2.192***	-0.954***	-2.322***	-0.040	-0.618***	-0.016	-0.754***	-0.053*	1.167***
	(0.057)	(0.283)	(0.050)	(0.137)	(0.036)	(0.123)	(0.026)	(0.0906)	(0.028)	(0.0814)
Plant, sector-year fixed effects; region-time trends	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	309491	31587	225404	30333	236861	30333	261588	29414	322065	39992
Underidentification	3196	144	1843	146	1844	146	2311	138	3176	323.2
Weak identification	2153	62	1271	63	1155	63	1488	59	2194	156

4.4 Performance Gains of Electricity-intensive Plants

Further support to the hypothesis that more productive technology is embodied in electric vintages of capital is showed in Figure 2 which compares electricity-intensive plants within narrowly defined industries.[29] The figure shows that in Indonesia, plants with

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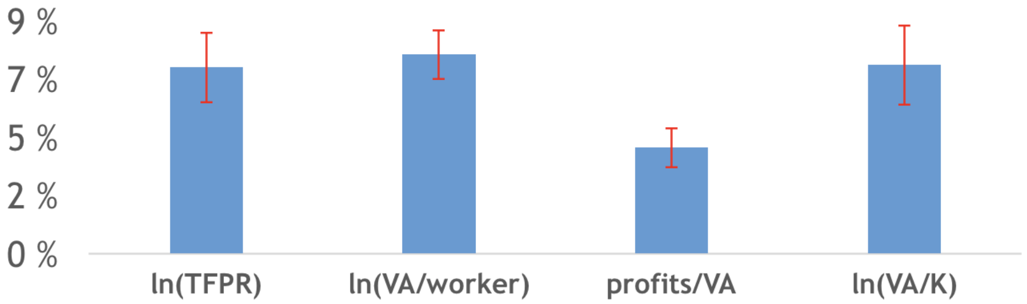
[28] Moreover, preliminary results suggest that the increase in turnover is stronger in fuel-intensive plants.

[29] Figures for Mexico are under constructions, but preliminary evidence is consistent with the findings for Indonesia

a share of energy consumption exceeding the 75th percentile of the distribution within each five digits sector and year, perform better. Electricity-intensive plants have 7% higher TFPR, 8% higher labor productivity, 5% higher profit margins and their capital stock is also 8% higher.

Figure 2: Comparison electricity-intensive plants vs others



4.5 Plants on the Technology Frontier

If our reading of the data is correct and an increase in fuel prices trigger technology upgrading in plants operating old vintages of capital, then the impact of fuel prices should be muted for plants which are more likely to operate the latest capital vintages. Table 3 shows that indeed this is the case, as the positive impact of fuel prices is lower for foreign plants.[30]

Table 3: Foreign plants and exporter

	(1)	(2)	(3)	(4)	(5)	(6)	(5)	(6)	(1)	(2)
	ln(TFPR)		ln(VA/worker)		ln(profits)		profits/VA		ln(VA/ENERGY)	
	IDN	MEX	IDN	MEX	IDN	MEX	IDN	MEX	IDN	MEX
ln(Price fuels)	0.298***	0.247***	0.230***	0.554***	0.214***	3.139***	0.090	0.0726***	0.230***	0.433***
	(0.050)	(0.0376)	(0.038)	(0.0983)	(0.057)	(0.569)	(0.056)	(0.0156)	(0.057)	(0.106)
ln(Price fuels)*foreign	-0.285**	-0.148***	-0.234***	-0.359***	-0.296***	-2.332***	0.223	-0.0491**	-0.180	-0.230*
	(0.130)	(0.0518)	(0.075)	(0.131)	(0.106)	(0.718)	(0.374)	(0.0230)	(0.114)	(0.133)
ln(Price electricity)	-0.003	-0.265***	0.029	-0.274***	0.032	-2.567***	-0.024	-0.0180	-0.062**	1.307***
	(0.025)	(0.0479)	(0.021)	(0.0825)	(0.029)	(0.546)	(0.021)	(0.0153)	(0.029)	(0.120)
ln(Price electricity)*foreign	0.041	-0.0135	-0.047	0.0420	-0.092	-0.167	-0.209	-0.0370	0.074	-0.652***
	(0.075)	(0.0754)	(0.063)	(0.158)	(0.088)	(1.159)	(0.241)	(0.0332)	(0.095)	(0.216)
Plant, sector-year fixed effects; region-time trends	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	258192	29157	325394	30572	315426	31586	325394	31571	322065	30171
Underidentification	156	28	533	27	565	30	533	30	542	93
Weak identification	38	5	126	5	132	6	126	6	128	22

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[30] Preliminary results from Indonesia suggest that foreign plants tend to be more electricity-intensive than domestic counterparts in the same narrowly defined sectors. Thus, the result is consistent with the idea that electricity-intensive plants have less room to adjust their capital equipment in response to fuel price increases.

5 Conclusion

Most of the literature on energy prices and plants' performance has focused on electricity. However, distinguishing between electricity and fuels is important because they power capital equipment of different types. In this paper, we test for the impact of both electricity and fuel prices, finding an asymmetric impact: electricity price hikes are detrimental for plants' performance, while fuel prices have a positive effect. To explain our result, we put forward the following hypothesis. Old technology is embodied in capital vintages that are more likely to be powered by fuel, while new technology tends to be embodied in electric capital vintages. An increase in fuel prices induces managers to scrap old fuel-powered machinery and purchase new electric equipment. Since electric machinery is more productive and energy-efficient, the negative effect of the fuel price increases is compensated by the positive effect on technological upgrading, with a potentially positive net effect on performance.

Our analysis is based on large nationally representative samples of manufacturing plants in two of the largest developing countries (Indonesia and Mexico). In this way, threats to external validity which typically affects single country empirical analyses are less of a concern in our framework. Our approach also implies that the results are not specific to a particular setting or identification strategy. We conclude that in developing countries, policies based on carbon taxes or subsidy reforms can not only be used to achieve environmental goals, but also to improve economic performance. Our estimates imply that a ten percent increase in fuel prices would lead to a 3% increase in total factor productivity for Indonesia and 1.2% for Mexico.

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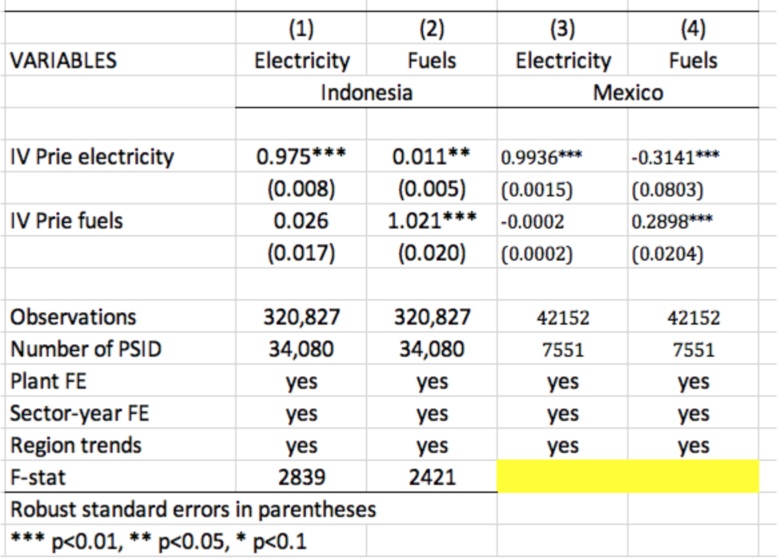
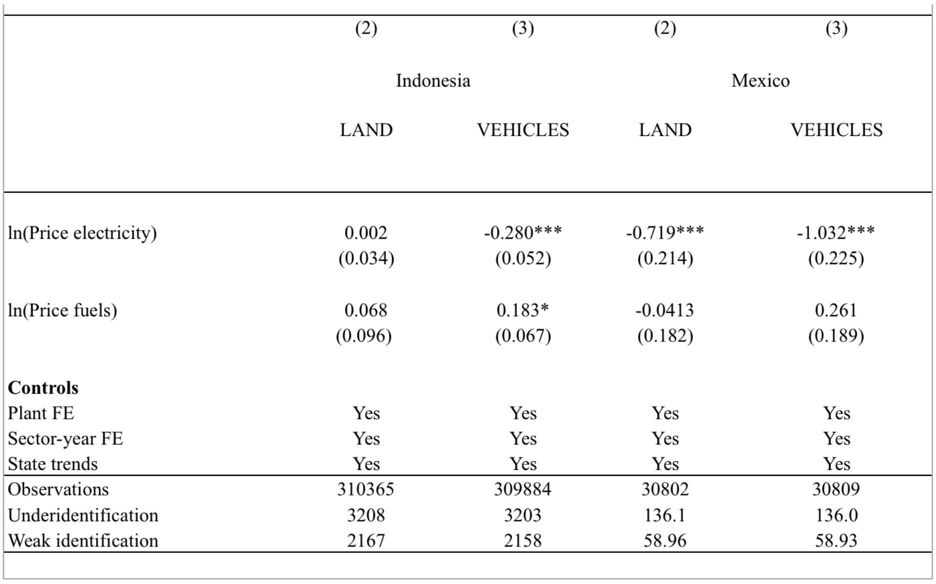
Table A1: First stage regression



	(1)	(2)	(3)	(4)
VARIABLES	Electricity	Fuels	Electricity	Fuels
	Indonesia		Mexico	
IV Prie electricity	0.975***	0.011**	0.9936***	-0.3141***
	(0.008)	(0.005)	(0.0015)	(0.0803)
IV Prie fuels	0.026	1.021***	-0.0002	0.2898***
	(0.017)	(0.020)	(0.0002)	(0.0204)
Observations	320,827	320,827	42152	42152
Number of PSID	34,080	34,080	7551	7551
Plant FE	yes	yes	yes	yes
Sector-year FE	yes	yes	yes	yes
Region trends	yes	yes	yes	yes
F-stat	2839	2421		
Robust standard errors in parentheses				
*** p<0.01, ** p<0.05, * p<0.1				

Table A2: Placebo experiment for impact of energy prices on other categories of assets.



	(2)	(3)	(2)	(3)
	Indonesia		Mexico	
	LAND	VEHICLES	LAND	VEHICLES
ln(Price electricity)	0.002	-0.280***	-0.719***	-1.032***
	(0.034)	(0.052)	(0.214)	(0.225)
ln(Price fuels)	0.068	0.183*	-0.0413	0.261
	(0.096)	(0.067)	(0.182)	(0.189)
Controls				
Plant FE	Yes	Yes	Yes	Yes
Sector-year FE	Yes	Yes	Yes	Yes
State trends	Yes	Yes	Yes	Yes
Observations	310365	309884	30802	30809
Underidentification	3208	3203	136.1	136.0
Weak identification	2167	2158	58.96	58.93

A Construction of Indonesian Capital Series

In order to avoid relying on depreciation rates, we tried to preserve the self-reported original values by the plant as much as possible and applied the PIM only to fill gaps. In this paper self-reported capital series were object of an extensive cleaning algorithm aimed at mitigating measurement errors.[31] Our algorithm consists first in replacing zero or negative values as missing observations and then applying a two-steps procedure based on capital-labor ratios (KL).For each year, we compute the average KL in each 4 digit KBLI sector over the whole sample, but excluding the years in which the average and total values of the capital stock exhibited suspicious jumps, i.e. 1996, 2000, 2003, 2006, 2009 and 2014. An observation is dropped is the ratio of plant-KL to the sector average KL is below 0.02 or larger than 50.[32] Then, in a second step we compare a plant KL in a given year with the average value of the KL within the same plant but in the other years of observation. An observation is dropped if the ratio of plant-year-KL to the plant average KL is below 0.2 or larger than 5. Plants are dropped from the sample in case the cleaning procedure results in all missing values of self-reported capital.

When a plant has some but not all valid observations for self-reported capital stock, then missing values are replaced by applying a forward/backward perpetual inventory method (PIM). Being only a fraction of the total observations , we rely less on estimates of depreciation rates.[33] Previous studies focus on the first year of observation of a plant, without assessing the plausibility of the data point. Since PIM series are very sensitive to the choice of the initial observation, especially with relatively short time series, the resulting capital stock could be severely mis-measured. Moreover, information on purchases and sales of capital equipment, which is subject to the same measurement errors of the reported capital. For such a reason, after filling missing values with the PIM we re-apply the two stages check described above in order to minimise the possibility of mis-measurement. As a final test, we compute plant-level growth rates of KL and we check that it is reasonably distributed (Figure A1). Figure A2 compares original and clean capital stock series.

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[31] One important problem with the reported series is that in some years, there are plants were characterised by implausible large values of capital. Studying the behaviour of the stock within plants reveals that in some circumstances plants reported values in different units. The phenomenon is somewhat more frequent in 1996 and 2006, when the BPS conducted a wider economic census that collected information in units rather than in thousand Rupiah. For instance, in 2006 the number of surveyed firms increased by 40%. The increase in coverage required hiring unexperienced enumerators that were more likely to make mistakes, which contributed to increase measurement errors.

[32] We experiment with stricter thresholds which result in too many observations dropped.

[33] We follow Arnold and Javorcik (2009) and assume that the annual depreciation rate for buildings is 3.3 percent, for machinery 10 percent, and for vehicles and other fixed assets 20 percent. For land, we assumed no depreciation.

Figure A1: Plants' growth rate distribution of capital-labor ratio.

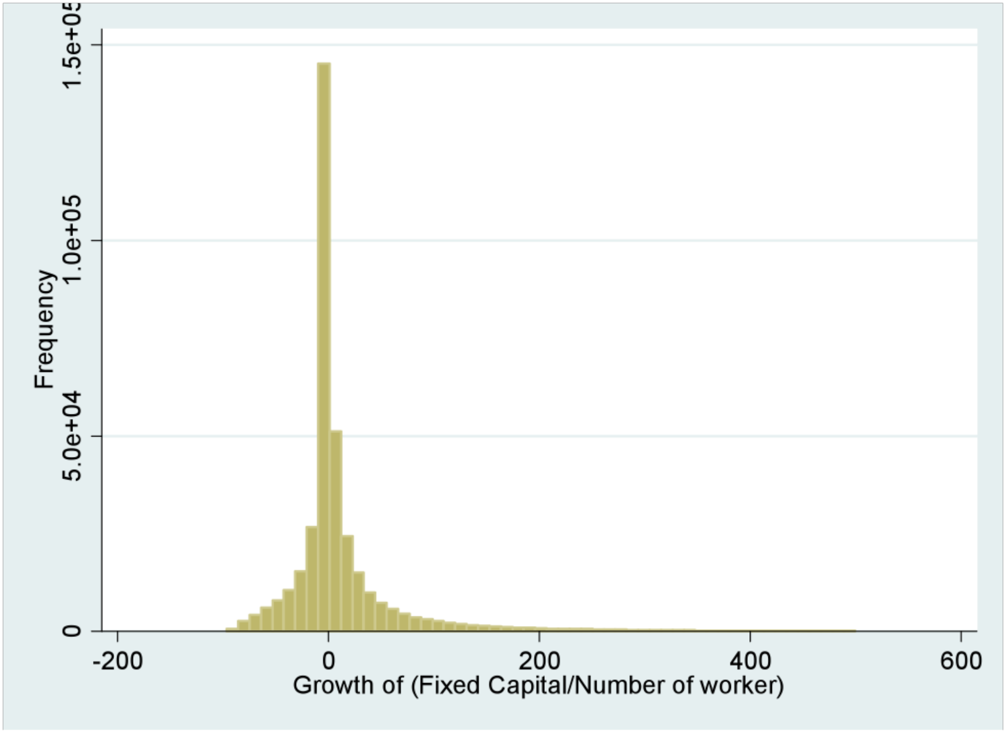

Figure A2: Comparison of Aggregate Nominal Capital Stock Series.