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The Drivers and Impacts of Water Infrastructure Reliability

A Global Analysis of Manufacturing Firms

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Abstract

Inadequate infrastructure impedes the productivity of manufacturing firms, with negative consequences for the wider economy. This study examines how water infrastructure copes with severe weather fluctuations and analyzes the effect of unreliable water supplies on the productivity of manufacturing firms, focusing predominately on firms in developing economies. This is achieved using firm-level data from World Bank Enterprise Surveys covering more than 16,000 manufacturing firms in a cross-section of 103 countries between 2009 and 2015. The study finds that periods of significantly low rainfall lead to higher water outages, and that the overall impact is driven by the effects of drought on low-income and lower-middle-income economies, with upper-middle-income and high-income economies benefitting from more resilient water infrastructure. Furthermore, the study finds that incidents of water outages lead to lower firm productivity for firms in less developed economies. For the average firm located in a low-income or lower-middle-income economy, one additional water outage incident per day in a typical month can lead to losses of approximately 8.2 percent of annual sales. This finding calls for increased policy focus on water infrastructure services, particularly in poorer countries where water infrastructure and firms seem to be particularly vulnerable to the vagaries of rainfall.

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The Drivers and Impacts of Water Infrastructure Reliability – A Global Analysis of Manufacturing Firms[1]

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to the vagaries of rainfall.

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1. Introduction

Inadequate infrastructure and low productivity of manufacturing firms tend to be closely related, especially in developing economies (Tybout 2000; World Bank, 1994; Bloom et al., 2010). A substantial literature has linked infrastructure quality to economic performance (Calderón et al., 2003; Canning, 1998; Jiemenex, 1995). However, fewer studies, typically region-specific, have established a link between infrastructure and the performance of the private sector. This is in sharp contrast to the large literature focusing on access to finance and firm performance (Davis et al. 2001). Furthermore, infrastructure encompasses roads, ports, power, communication facilities, and water, with the latter receiving less attention than the others (for example, Arnold et al., 2008 consider how communication and electricity infrastructure, and financial services affect firm performance in Sub-Saharan Africa, but do not consider the importance of water). Evidence of the lower prominence given to water infrastructure can also be seen in the World Bank's Enterprise Surveys, which have the broadest and most consistent coverage of firm-level data globally. While the surveys do contain information on water outages, the questionnaire does not consider access to or reliability of water as a potential obstacle for operations. Specifically, when respondents are asked to rank the top obstacles they face – a legacy question that has existed since the inception of the surveys – the choices encompass power, communication, and transportation, while water is not presented as an option. Similarly access to water and water infrastructure does not feature in the World Bank's *Ease of Doing Business Index* while electricity is included. However, one would expect this to change in the near future, given the increased focus on climate change that has brought the issue of looming water challenges to the frontlines of policy.

The sidelining of water as an area of focus is surprising given its importance in driving the economy. Consider, for example, the prominent role water plays in the Sustainable Development Goals (SDGs). The SDGs were conceived to reflect the holistic nature of development and the integrated approach needed to end poverty, protect the planet, and ensure prosperity for all. The end result is 169 targets revolving around 17 goals. Water is unique in that it links nearly every SDG (World Bank, 2016). On top of SDG 6, which directly concerns clean water and sanitation, water is also crucial for food security (SDG 2), health (SDG 3), clean energy (SDG 7), new jobs (SDG 8), and the planet's ecosystem (SDGs 13,14, and 15). Therefore, it is implicitly acknowledged that water affects the private sector through a myriad of channels both directly and indirectly. More recently, the relationship between water and economic development has been highlighted by Distefano and Kelly (2017). The authors use a multi-region, input-output model to show how water scarcity may threaten economic growth. The myriad of ways in which uncertain water supplies may impact development have also been highlighted in a recent World Bank report (Damania et al., 2017).

A first step to exploring the complex pathways by which water affects the private sector is to establish a set of narrower relationships – what are the potential determinants of poor water infrastructure, and what influence does water infrastructure quality have on firm performance? With regards to the former, an interesting question is – to what extent the water infrastructure can cope with extreme rainfall variability? Analysis by Kumar et al. (2014) suggests that climate change will result in more frequent wet spells in more humid areas, and more frequent dry spells in more arid ones. This may have asymmetric impacts across countries, as economies in the developing world may have water supply infrastructure that is ill equipped to cope with the weather extremes. That poorer countries may suffer more in the case of water shortages has been illustrated by Distefano and Kelly (2017). The authors show that virtual water trading and increased efficiencies of water use can alleviate the impact of scarcity, but that the effectiveness of these policies will be limited in poorer countries.

It is important to consider the potential link between water supply reliability and firm productivity. It is feasible that water infrastructure quality may have little effect on firm performance, and that the relegation of water as an unimportant factor in the business environment may not be a mere oversight. It also could be that firms in many economies have taken measures and adapted production strategies to an environment of poor water infrastructure. With the use of alternative sources of water, water outages may be business as usual for firms and thus have limited impact on firm performance. These issues yield several research questions which this study explores. First, does weather variability significantly impact water supply? Second do water outages have any effect on firm performance? Third, what might the magnitude of this effect be? And, finally, are there asymmetric impacts across levels of economic development?

This is the first study to use firm-level data to investigate how well water infrastructure can cope with extreme weather variability. It is also the first study of the effect of water infrastructure quality on firm performance that is truly global in nature. Thus far, the handful of studies on water infrastructure quality and firm performance have tended to focus on a specific region such as Sub-Saharan Africa (Moyo, 2011; Escribano et al., 2010, Davis et.al, 2001) or Eastern Europe and Central Asia (Iimi, 2011; Bogetic and Olusi, 2013). Furthermore, most of these studies are based on a small number of countries (Moyo, 2011) or construct their own data for a specific country (Davis et.al, 2001). Finally, all previous studies based on World Bank Enterprise Surveys use data from early rounds that were not nationally representative (Iimi, 2011; Moyo, 2011; Escribano et al., 2010; Bogetic and Olusi, 2013).

The findings of these studies have not led to a definitive conclusion on whether and how much water infrastructure reliability impacts firm performance. On the one hand, deficiencies in water supply are found to be the largest impediment to firm productivity in the Russian Federation using Enterprise Surveys conducted between 2003 and 2008 (Bogetic and Olusi, 2013). The Enterprise Surveys conducted in 2005 also found that water shortages add to firms' costs in the Eastern Europe and Central Asia region (Iimi, 2011). Similarly, Moyo (2011) using Enterprise Survey data for five economies - South Africa, Zambia, Uganda, Mauritius and Tanzania, between 2002 and 2005, finds poor water infrastructure quality has a negative effect on firm productivity. More recently Islam (forthcoming) has illustrated the extreme impact that water shortages can have on informal firms, which are an important source of employment in the developing world. On the other hand, Davis et al. (2001) find a small effect of water infrastructure improvement on expenditures of small enterprises. Escribano et al. (2010) use earlier Enterprise Surveys for 26 African countries conducted between 2002 and 2006 to explore the effect of infrastructure quality on firm productivity and only find an effect for slower growing African economies. Typically, studies using firm-level data have been relatively silent on the possibility of endogeneity of firm-level infrastructure measures, pointing out instead that disaggregated infrastructure measures do not suffer several endogeneity concerns faced by aggregated public capital measures found in macro-level studies (Escribano et al., 2010; Moyo, 2011). Macro-level studies have not found robust results with regards to infrastructure and growth, although a few studies employing different tools to address endogeneity have found some positive and significant effects (Roller and Waverman, 2001; Shioji, 2001).

This study makes several distinct contributions to the extant literature, specifically it: (i) explores how well water infrastructure can cope with extreme weather variability across a wide range of countries, most of which are in the developing world – where water infrastructure is likely to be less robust, (ii) establishes the relationship between water infrastructure quality and manufacturing firm performance using nationally representative firm-level data for 103 economies, (iii) quantifies the magnitude of this effect, and (iv) presents results that are differentiated by income level, according to the World Bank income classification.[2] The rest of the paper is structured as follows. Section 2 presents the data, section 3 outlines the empirical specifications used to examine, first, the impact of extreme weather events on water supply, and, second, to analyze the effect of supply shortages on firm performance, while section 4 presents the results of these analyses. Section 5 presents several robustness checks; finally, section 6 concludes.

2. Data

The firm-level data source is the World Bank Enterprise Surveys. For the analysis, over 16,000 manufacturing firms covering a cross-section of 103 countries between 2009 and 2015 are used.[3] The Enterprise Surveys (ES) provide a suitable data source for our analysis for several reasons. First, the surveys are nationally representative, stratified by location (within country), firm size, and sector. Second, the data are comparable across economies; the Enterprise Surveys (ES) use a standard survey instrument to collect data employing the same methodology across all countries; they target business owners and top managers of firms as respondents. Third, the surveys have high coverage in terms of countries and topics including access to finance, corruption, infrastructure, crime, competition, labor, business environment obstacles, and performance. The comparability of data across countries as well as the high coverage is a rarity given that many survey data sets face issues of low country coverage, no comparability across countries, or both. The Enterprise Surveys restrict the universe of firms given the nature of the questionnaire. The universe excludes extractive industries, agriculture, informal firms (not registered), fully government-owned enterprises and micro firms with fewer than five full time employees.

[2] https://datahelpdesk.worldbank.org/knowledgebase/articles/906519-world-bank-country-and-lending-groups
[3] For a complete list of the countries included in the analysis, please refer to Table A2 of the Appendix.

There are two indicators of water infrastructure utilized in our analysis. The first is the number of incidents of water shortages per day in a typical month. Firms are asked how many incidents of insufficient water supply their establishment experienced in a typical month, over the last fiscal year. The mean of the number of water shortages per day in a typical month in the sample is 0.02, which translates to about 11 water shortages per year. The second measure is the average duration of water outages in hours. This measure takes a value of zero for firms that do not experience any water shortages. The mean value for the sample (including those firms that did not experience any outages) is 0.86 hours. For the sample of firms that experienced water outages, the average duration of a water shortage is approximately 10 hours.

Our analysis also includes corresponding measures of electricity infrastructure, as the performance of water and electricity infrastructure may be correlated, and we do not wish to confound one with the other. As with the water indicators, measures of electricity infrastructure performance include the number of power outages per day in a typical month and the average duration of these outages. The mean of the number of power outages per day in a typical month is 0.26, which translates to about 119 power outages per year. The mean value for the duration of power outages for the whole sample is 2.19 hours. For the sample of firms that experienced power outages, the duration of a power outages is approximately 4 hours. These statistics show that fewer firms experience water shortages than electrical outages, but for those that do, water shortages last far longer than electrical outages. Summary statistics are presented in table 1, while descriptions and sources of variables are presented in table A1.

The ES data are combined with weather data obtained from Matsuura and Willmott (2012a,b). The weather data set contains monthly observations of precipitation and average temperature at the 0.5-degree grid cell level. The data are transformed into average monthly temperature, and total precipitation (mm), per year, for each grid cell. Rather than analyzing the impact of rainfall averages, we look at the impact of rainfall "shocks", i.e., unanticipated deviations from average values. To account for the non-normal distribution of rainfall, the raw rainfall data are converted to a Standardized Precipitation Index, following the methodology outlined by Neves (2015), before calculating the "shocks"; further details are provided in the next section. As illustrated in table 1, droughts (SPI<-1.5) are a more common occurrence than situations of abundant rainfall (SPI>1.5)

– on average, about 12% of the grid cells included in our sample experienced a drought, while approximately 6% recorded abundant rainfall conditions.

3 Empirical specification

3.1 Modelling the impact of extreme weather on water supply interruptions

To analyze the relationship between water shortages and weather variability, we look at the impact of rainfall and temperature within a location defined by a 0.5-degree grid cell. However, average temperatures and precipitation levels may be endogenous given that firms may choose to locate in areas of moderate precipitation and temperature. Thus, rather than focusing on average rainfall, our main variables of interest capture the frequency of rainfall shocks, specifically, unanticipated deviations in annual amounts of rainfall from long-run local averages. While the relationship between firm outcomes and average weather patterns may be endogenous, shocks to such long-run averages should be exogenous. Before calculating rainfall shocks, the raw rainfall data are converted to the Standardized Precipitation Index (SPI), to account for the non-normal distribution of rainfall. Positive rainfall shocks are then defined as periods when the SPI has a value of 1.5 or higher; i.e., situations when the normalized rainfall data are 1.5 standard deviations above the long-run mean for that grid cell. Negative rainfall shocks are situations in which the SPI has a value of -1.5 or less. The +/-1.5 SPI thresholds were deliberately chosen to analyze how drought conditions impact water outages for firms; according to the climatology literature, an SPI value of -1.5 or lower is reflective of drought conditions (McKee et al., 1993). Two dummy variables are used to capture the impact of drought and of large positive rainfall shocks. The first model we estimate is outlined in equation (1) below:

$$
\begin{aligned}
WaterOutage_{irj} &= \gamma_1 Large\_Pos_{irj} + \gamma_2 Large\_Neg_{irj} + \gamma_3 \varphi_{irj} + \gamma_4 region_r/country_c \\
&\quad + \gamma_5 sector_j + \epsilon_{irj} \qquad (1)
\end{aligned}
$$

The dependent variable, $WaterOutage_{irj}$ is the number of water outages per day experienced by firm i in location r and sector j, in a typical month. $Large\_Pos_{irj}$ is a dummy variable equal to one if the SPI is above 1.5, $Large\_Neg_{irj}$ is a dummy variable equal to 1 if firm i experiences drought conditions, i.e., an SPI of -1.5 or less. The specification accounts for the following firm-level controls: firm size, age, access to finance, whether or not the firm invests in fixed assets, reported losses due to breakage or spoilage in transport (as proxy for transportation infrastructure), security costs, female ownership, exporting and ownership status (foreign versus domestic), use of foreign technology, formal registration, generator ownership, and electricity outages. These are comprised in the vector $\varphi_{i,r}$ in equation (1). All countries are pooled in the baseline regression, and we include region (within country) and sector fixed effects ($region_r$ and $sector_j$). In the regressions that include the rainfall shocks, we replace region fixed effects ($region_r$) with country fixed effects ($country_c$). The reason for this is that the geographical units of the weather observations are of similar size to regions within a country, and thus the inclusion of region fixed effects absorbs much of the variation in the weather variables. Finally, $\epsilon_{i,r}$ represents a random error term. Survey weights are applied in all estimations.

3.2 Modelling the impact of poor water supply on firm performance

Through equation (1), we ask how well water infrastructure can cope with rainfall shocks; as a next step, we take this analysis further and ask whether inadequate water infrastructure may be detrimental for the total factor productivity (TFP) of a firm, which in turn may lower output. Theoretically, estimating this impact is a two-stage process – first estimating the production function and obtaining the estimates of TFP. Second, estimating the effect of the infrastructure variables on the resulting TFP. However, this approach is problematic. Omitting the infrastructure variables in the estimation of the production function will result in omitted variable bias and thus incorrect estimates for TFP (Wang and Schmidt 2002; Moyo 2011). A common approach is to therefore include the determinants of TFP and output into one equation. We adopt this approach and estimate the following equation assuming a translog production function[4]:

[4] The water infrastructure and firm productivity literature has adopted different functional forms. A few studies have estimated Cobb-Douglas production functions (Bogetic and Olusi, 2013; Arnold et al., 2008; Moyo, 2011) while others have estimated translog production functions or translog cost functions (Escribano et al., 2010; Iimi, 2011). As it is a more flexible functional form relative to the Cobb-Douglas, we opt-for a translog specification for the production function. The estimation of a translog cost function has also been used for power infrastructure and firm productivity estimations (Fisher-Vanden et al., 2015). Due to revisions in the cost section of the Enterprise Surveys over time, estimating a cost function would be challenging. Thus, we estimate a production function.

$$lnsales_{irj} = \beta_L lnL_{irj} + \beta_K lnK_{irj} + \beta_M lnM_{irj} + \beta_{W1} W1_{irj} + \beta_{W2} W2_{irj} + \beta_{E1} E1_{irj} + \beta_{E2} E2_{irj} + \beta_{LL} \frac{1}{2} lnL_{irj}^2 + \beta_{KK} \frac{1}{2} lnK_{irj}^2 + \beta_{MM} \frac{1}{2} lnM_{irj}^2 + \beta_{LK} lnL_{irj} lnK_{irj} + \beta_{LM} lnL_{irj} lnM_{irj} + \beta_{KM} lnK_{irj} lnM_{irj} + \beta_X X_{irj} + \gamma_1 region_r + \gamma_2 sector_j + \epsilon_{irj} \quad (3)$$

To ensure the production function is well behaved, standard constraints including linear homogeneity in inputs and symmetry are imposed:

$$\beta_{LL} + \beta_{LK} + \beta_{LM} = 0$$

$$\beta_{KK} + \beta_{KL} + \beta_{KM} = 0$$

$$\beta_{MM} + \beta_{ML} + \beta_{MK} = 0$$

$$\beta_{ij} = \beta_{ji}, i, j = K, L, M$$

Where $lnsales$ is the log of annual sales of firm i in region (within-country) r, and sector j over the last fiscal year. The inputs include the log of labor (lnL), log of capital (lnK), and the log of raw materials or intermediate inputs (lnM). Labor is defined as the number of full-time employees. Capital is defined as the cost for the firm to re-purchase all its machinery. The main variables of interest are indicators of water infrastructure, $W1$ and $W2$, which represent the number of water shortages and their duration, respectively. The estimation also accounts for corresponding measures of electricity infrastructure, $E1$ and $E2$, again representing their number and duration. As in equation (1), in the estimation of equation (2) we pool countries and include region (within country) and sector fixed effects. The effects of the infrastructure variables are assumed to be Hicks neutral. As a robustness check, we also present the results using a Cobb-Douglas production function.

Several factors affect the productivity of firms. Firm productivity may vary by the age of the firm and whether the firm is foreign owned (Harris and Robinson, 2003; Huergo and Jaumandreu, 2004; Biesebroeck, 2005; Bigsten and Gebreeyesus, 2007; Haltiwanger et al., 2013). Firms with generators may have adapted to power outages that would lower productivity, and thus we include a dummy variable that takes a value of 1 if a firm has a generator and 0 otherwise. The inclusion of this dummy is motivated in part by the findings of research by Cole et al. (2018) who show that, for firms with generators, power outages have no impact on sales. Trade is also found to be an important determinant of firm productivity (Lopez, 2005; Bernard et al., 2007). We proxy for exporting firms by including a dummy variable that takes the value of one if 10% or more of a firm's sales originates from exports, and 0 otherwise. Firms that offer formal training can also raise productivity (Black and Lynch, 1996), thus we include a dummy variable that takes a value of 1 if the firm offers formal training, and 0 otherwise. There are several factors that may have come into play in a firm's choice of location or input mix. We control for such variables as much as possible. As in the estimation of equation (2), we proxy for transportation infrastructure through the losses experienced by firms due to breakage/spoilage of products shipped domestically. Similarly, we account for firms' expenditure on security, such as equipment, personnel, or professional security services to prevent crime. Finally, informal firms may be more vulnerable to infrastructure shocks as they may not have the resources to adapt. While informal firms are not part of the sample, there are firms that may be similar in characteristics to informal firms. We capture this using two variables – one is the number of years for which a firm operated informally since it began operations, and second whether the firm competes with informal firms. To summarize, the firm characteristics that we control for are: foreign ownership, export status, age, formal training, electricity generator ownership, losses due to breakage/spoilage of products shipped domestically, security costs, the number of years that firm was unregistered at start, and competition with informal firms. These are comprised in the vector X in equation (2).

While the focus of this paper is to obtain estimates of the effect of water disruptions on firm output, it should be noted that there are other concerns. A wider literature has noted that the choice of the basic inputs such as capital, intermediate inputs, and labor may be endogenous given that firms choose these inputs, and the choice of inputs may be determined by unobservable factors (Ackerberg et al., 2015; Olley and Pakes, 1996; Levinsohn and Patrin, 2003). This would produce inconsistent estimates for the coefficient of the inputs. Furthermore, productive firms may choose to locate in areas with good infrastructure. This is likely to bias upward any effect of water shortages on sales. On the other hand, firms that went out of business due poor infrastructure services are omitted from the sample. Furthermore, most firms in our sample are located in urban areas where water infrastructure is generally better, thus, the relationship between water shortages and sales may be attenuated as the firms we observe may be better able to cope due to better infrastructure compared to firms located in rural areas. These two facts are likely to bias downward the effect of water shortages and sales. While this study cannot completely rule out endogeneity, factors that may influence firms' choices of inputs such as location are accounted for in the regressions as covariates within the confines of data availability. The inclusion of a rich set of firm-specific control variables, as discussed above, should minimize any endogeneity.

4. Results

4.1 The impact of extreme weather variability on water supply

We first consider how well the infrastructure in the countries we consider can cope with unanticipated fluctuations in rainfall. Table 2 presents the main results from the estimation of equation (1). In the first column, we omit the precipitation shock variables and explore the correlations between water outages and various firm characteristics. The only statistically significant finding is that firms that have a checking or savings account experience fewer water outages. In column 2 we include the positive rainfall shock and drought variables and replace the region fixed effects ($region_r$) with country fixed effects ($country_c$).[5] The results displayed in column 2 show that, on average across our sample, drought conditions lead to greater water shortages, the coefficient is significant at the 1 percent level. Large positive rainfall shocks have, on the other hand, no impact of water outages.

The findings presented in Table 2 may not just reflect the impact of drought on water supply, but also its impacts on electrical outages. Water towers located in high geographical areas typically deliver water to firms and households through pipes. However, electricity is needed to operate pumps that refill the water towers. Thus, electrical outages can also lead to water shortages. Thus, we also include power outages as an additional covariate. Power outages are positively related to water outages, with a coefficient statistically significant at the 1 percent level. However, they do not detract from the direct effect of drought on water outages. The implication of these findings is that droughts can create significant stress on the water infrastructure. Thus, rainfall variability due to climate change can incur important costs to the private sector through water infrastructure unreliability.

[5] As noted in Section 3, this is because the inclusion of regional fixed effects absorbs much of the variation in the weather variables.

In columns 3 and 4 of Table 2, we explore whether the impacts of rainfall shocks on water infrastructure may vary according to a country's level of economic development. Column 3 shows that, in low and lower-middle income countries, firms that experience a drought are subject to an additional 0.14 water interruptions in a typical month – this represents a nearly four-fold increase relative to the mean across these countries, where the average firm experiences 0.037 outages in a typical month. In upper-middle income and high-income economies, however, droughts do not result in an increased number of water outages. These asymmetric effects are further highlighted by an additional result – column 3 also shows that firms in low and lower-middle income economies do not report fewer outages in times of abundant rainfall, but firms in upper-middle and high-income economies do (column 4). This suggests that, not only is the water infrastructure in poorer countries less able to cope with drought conditions, it is also ill-equipped to take advantage of periods of abundant rainfall.

4.2 The impact of water shortages on firm performance

As the results of the production function estimation, presented in column 1 of table 3, show, the main inputs – labor, capital, and intermediate inputs – all have positive and significant coefficients. Our results show that water shortages have a significant, negative impact of firms' output. As illustrated in Table 3 (column 1) one additional shortage in a month reduces annual sales by 8.7 percent. The average duration of water shortages has, on the other hand, no statistically significant effect.

Table 3, column 1 also suggests that the electricity infrastructure variables do not have a statistically significant relationship with sales; however, this does not necessarily imply that electrical outages do not impact firm performance. Some firms may have adapted to frequent interruptions in electricity supply by purchasing a back-up generator.[6] Indeed, the coefficient on the variable indicating ownership of a generator is positive and highly statistically significant, suggesting that electricity outages may have no impact on output because firms have adapted to deficits in electricity infrastructure by securing access to a source of back-up generation. Having

[6] Unfortunately, the survey contains no equivalent information on access to alternative water supplies.

to adapt to outages by purchasing a back-up generator is not an ideal scenario for firms, and thus our results are unlikely to be capturing the nuanced ways in which electricity outages affect firms.[7]

Table 3 also shows that foreign ownership and exporting status are positively related to sales, with coefficients statistically significant at the 5% level. Formal training is positively related to sales, but the coefficient is not significant. As expected, security costs are negatively related to sales, with the coefficient statistically significant at the 1% level. Finally, the coefficient for the variable capturing whether or not firms compete with informal firms is negative but not statistically significant.

For this study, the translog production function is the base specification and all findings discussed above are based on this specification. However, we also present the results from estimating a Cobb-Douglas production function (column 2 of table 3) to show the robustness of our findings to an alternative functional form commonly used in the literature. Survey weights are used in all the estimations, taking advantage of the levels of stratification by sector, size, and location.

Just as our results presented earlier have shown that the impact of drought on water supply is asymmetric across income level, it is also plausible that the relationship between water shortages and productivity also differs according to countries' levels of economic development. Again, we explore the findings for two income groups – upper-middle and high-income economies on one hand and lower-middle and low-income economies on the other hand. The findings for both groups are presented in columns 1 and 2 of table 4. The results show that the number of water shortages per day has a negative and statistically significant coefficient for low and lower-middle income countries, but is not statistically significant for upper-middle and high-income economies. This result serves to underscore our earlier finding that there is an increased vulnerability to water shortages in less-developed economies. And that, unlike in low and lower-middle income economies, firms in high income economies appear to have the necessary resources to adapt to water shortages.

[7] Allcott et al. (2016) found that, for Indian manufacturing firms, average productivity losses due to electricity outages are small because, for the firms in their analysis, most inputs can be stored during such outages. Furthermore, their analysis shows that electrical outages more severely affect firms without generators relative to firms with generators. This has recently been shown to be the case for firms in Sub-Saharan Africa also, by Cole et al. (2018).

In order to dig deeper into these findings, we ask if the average impact of water shortages on firm output across our sample differs for water-intensive industries. More water-intensive industries may react differently to water shortages. For instance, water-intensive industries may on the one hand be more vulnerable to water shortages than non-water-intensive industries, or, on the other hand, may be more likely to have adapted to water infrastructure deficits by, for example, securing access to alternative water sources to those supplied by public utilities. Thus, the sample is split into two – one with water-intensive manufacturing industries and the other with other manufacturing industries that are not water-intensive. The water-intensive manufacturing sectors are chemicals, basic metals, paper, food, and refined petroleum.[8] Results are presented in columns 1 and 2 of table 5. Water shortages have a negative effect on sales regardless of the water intensity of the manufacturing sectors, statistically significant at the 10% percent level. However, the magnitude is almost twice as large for water-intensive sectors as non-water intensive sectors. This finding highlights the vulnerability of water-intensive sectors to poor water infrastructure.

Magnitude of the effects

In table 6 we present the magnitude of the effects. An additional increase in water outage incidents in a day experienced by a firm can lead to annual average losses of around US$1,052,645. This represents about 8.7% of the average annual sales of manufacturing firms in the sample. For firms in low and lower-middle income economies, such an increase in the frequency of water outages could reduce sales by US$1,082,400 (an 8.2% loss based on average firm sales in these economies). As Table 6 shows, the elasticity between water shortages and sales is 0.002; that is, a 1% increase in water shortages per day results in an approximately 0.002% decline in sales. A one standard deviation increase in incidents of water shortages per day (equivalent to 0.19 extra shortage) results in a loss of US$268,699 in revenues for the average firm in our sample, which is about 1.8% of the average revenues. For firms in low and lower-middle income economies, a one standard deviation increase in outages is associated with US$271,628 in lost revenues.

[8] Water intensity can differ for the same industry across economies. Economies can use different amounts of water to manufacture the same product. Data on water intensity for specific manufacturing industries in developing economies are sparse, thus the categorization of water-intensive industries is based on data from European economies. Sources: http://ec.europa.eu/eurostat/statistics-explained/index.php/Water_use_in_industry#Water_use_in_industry, http://www.wrap.org.uk/sites/files/wrap/PAD101-201%20-%20Manufacturing%20sector%20water%20report%20-%20FINAL%20APPROVED%20for%20publication%20-%2012,03,12.pdf

5. Robustness checks

In this section, we consider several robustness checks. First, we explore whether any additional results can be uncovered by looking at the combined impact of electricity and water outages. Second, we consider whether additional control variables affect our main results. Third, we test an alternative modeling approach - a stochastic frontier analysis – to see whether we obtain similar results to our base findings. And finally, we explore if taking the natural log of the infrastructure variables alters the results.

(1) Accounting for the links between water and power outages

It is plausible that the effect of water outages on sales may be accentuated by coinciding electrical outages. Therefore, in table A3, column 1 we interact power outages with water outages, and the duration of water outages with the duration of electrical outages. The coefficient on the interaction between water outages and electrical outages is not statistically significant at conventional significance levels. However, the number of water shortages per day alone retains a negative coefficient that is statistically significant at the 10 percent level. This indicates that while water outages have a negative impact on firms' output, this impact is not exacerbated by the frequency of power outages, perhaps again due to the availability of back-up sources of electricity generation.

(2) Including additional control variables

We next examine whether the findings on the impacts of infrastructure on output are robust to the inclusion of a number of additional covariates that have been used in the literature. These covariates are not included in the main regression models due to non-response by firms, which reduces the number of observations available for the analysis. These include bribery, investment, government ownership, and access to a line of credit or loan (Pless and Fell, 2017). As shown in column 2 of table A3, the number of water shortages per day retains a negative coefficient, statistically significant at the 5% level. Of the new control variables, only whether or not the establishment has a loan or line of credit has a statistically-significant coefficient. The coefficient is positive as expected.

(3) A stochastic frontier analysis

As a robustness check we use stochastic frontier analysis to explore the consistency of our production function results. The stochastic frontier approach includes an additional component to the random error in a traditional regression model. The additional component is an unobservable random variable that captures technical inefficiency (Battese and Broca, 1997). We assume an exponential distribution for the inefficiency term. By letting various firm characteristics determine inefficiency, several policy implications or behavioral responses can be uncovered that contribute to inefficiency (Liu and Myers, 2009). Results are presented in table A4. As indicated in column 2, the number of water outages per day in a typical month has a positive coefficient that is statistically significant at the 1 percent level. Thus, the number of water shortages results in greater inefficiency for the firm. This is consistent with our main findings in table 3.

(4) Taking natural logs of infrastructure variables

The infrastructure variables in the translog specification in table 3, column 1 are not in natural log form due to the number of zero observations. In table A5 in the appendix, we present the results using log transformations of the infrastructure variables. The negative and statistically significant effect of water outages on sales is retained, although the magnitudes of the coefficients should be taken with caution given the number of zero observations in the variables.

6. Conclusions

This study brings to light several new insights into the causes and consequences of unreliable water infrastructure for manufacturing firms. First, our research highlights that, across the globe, manufacturing firms are vulnerable to the impacts of drought on water supplies. Furthermore, we find that the overall impact is being driven by the effect in low and lower-middle income economies, while wealthier economies appear to have water infrastructure in place that is sufficient to buffer the impacts of unanticipated drought episodes. With the impacts of climate change likely to cause an increase in the frequency and severity of droughts experienced in certain regions, these results serve to highlight one of the vulnerabilities of the private sector in less-developed countries to the consequences of changing weather patterns – a vulnerability that has, heretofore, been largely overlooked.

Going beyond this, we find that unreliable water supplies have a negative impact on firm output that is both statistically and economically significant. This result is robust to different functional forms and passes several sensitivity analyses. In addition to showing that the manufacturing sector suffers from poor quality water infrastructure, we also show that the problem is more acute in low and lower-middle income countries, and in water-intensive sectors, providing further evidence that the consequences of a changing climate will not be equally borne. Such countries and sectors may need to consider policies to improve the reliability of their water infrastructure, or to boost their resilience to interruptions in water supplies.

This study is the most globally comprehensive to date, and the first to cover an extensive number of economies using data that are both internationally comparable and nationally representative. However, our analysis is limited by certain data constraints. For example, the study is silent on the extent of water usage for each of the firms, and on the availability of alternative sources of water to firms.

With a changing climate and increasing urbanization, the problems of poor water infrastructure in many countries may be exacerbated in the foreseeable future. The effect on the private sector will only increase in magnitude unless steps are taken to improve water infrastructure. In the face of looming water challenges, this study also intends to sound a rallying cry for the need for high-quality data on water infrastructure quality and water use by the private sector to better serve the needs of future research in this area.

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Table 1: Summary Statistics

	Observations	Mean	Std. Dev.	Min	Max
Log of sales	16,847	12.92	2.11	4.78	23.35
Log of labor (lnL)	16,847	3.14	1.21	0.00	9.41
Log of capital (replacement value) (lnK)	16,847	11.31	3.80	-18.42	24.33
Log of raw materials (costs) (lnM)	16,847	11.38	3.74	-18.42	22.59
Sales (in USD)	16,847	12,100,000	256,000,000	119	13,900,000,000
Total number of full time employees, adjusted for temporary workers	16,847	68	278	1	12,150
Cost for establishment to re-purchase all its machinery (in USD)	16,847	7,335,669	271,000,000	0	36,900,000,000
Cost of raw materials and intermediate goods used in production (in USD)	16,847	3,017,798	75,800,000	0	6,470,000,000
No. of water shortages per day in a typical month (all)	16,847	0.02	0.19	0	12
Average duration of water shortage	16,847	0.86	4.94	0	300
No. of electrical outages per day in a typical month	16,847	0.26	0.79	0	21
Average duration of electrical outages (hours)	16,847	2.19	12.62	0	1088
Firm owns or shares a generator Y/N	16,847	0.27	0.44	0	1
Losses due to breakage/spoilage shipped domestically (% of value of the products)	16,847	0.97	3.77	0	100
Log of age of firm	16,847	2.66	0.78	0	5.21
Foreign ownership Y/N	16,847	0.11	0.32	0	1
Exports 10% or more of sales Y/N	16,847	0.17	0.37	0	1
Security costs (% of sales)	16,847	1.26	3.72	0	96.95
Establishment competes against unregistered or informal firms Y/N	16,847	0.56	0.50	0	1
No. of years that firm was unregistered at start	16,847	0.97	4.33	0	90
Formal training Y/N	16,847	0.33	0.47	0	1
Expected to give gifts to public officials (to get things done) Y/N	15,633	0.22	0.41	0	1
Ownership - government/state (%)	16,843	0.32	4.50	0	99

Purchased fixed asset Y/N	16,798	0.47	0.50	0	1
Establishment has a line of credit or loan	16,700	0.40	0.49	0	1
Bribery depth	18,394	15.23	33.12	0	100
Bribery incidence	18,394	0.20	0.40	0	1
Informal payment/gift requested for water connection Y/N	1,029	0.21	0.41	0	1
Proportion of public transactions (excluding water) where a gift or informal payment required	938	0.24	0.38	0	1
Firm experienced at least one public transaction (excl. water) where a gift or informal payment was required Y/N	938	0.32	0.47	0	1
Wait for water connection (days)	1,029	40.55	83.28	1	1095
Establishment has checking or savings account Y/N	1,029	0.84	0.36	0	1
Female manager Y/N	1,029	0.1269	0.333	0	1
Use technology licensed from foreign companies Y/N	1,029	0.21	0.41	0	1
Severe positive precipitation shock severe (SPI > 1.5)	24,747	0.06	0.23	0	1
Severe negative precipitation shock (SPI< -1.5) - Drought	24,747	0.12	0.33	0	1
Average historical temperature 1900-2014	24,747	20.11	6.95	-8.88	31.04

Table 2: Determinants of Water Shortages

Y = No of water shortages per day in a typical month

	All economies		**High and Upper Middle Income**	**Low and Lower Middle Income**
	(1)	**(2)**	**(3)**	**(4)**
Positive precipitation shock severe (SPI)		0.001	-0.007**	0.003
		(0.009)	(0.003)	(0.013)
Negative precipitation shock very severe - Drought (SPI)		0.054***	-0.001	0.143***
		(0.005)	(0.003)	(0.012)
No of electrical outages per day in a typical month		0.057***	0.014***	0.062***
		(0.017)	(0.004)	(0.020)
Firm owns or shares a generator Y/N	0.007	0.011	0.009	0.014
	(0.008)	(0.009)	(0.007)	(0.015)
Firm size: Log of total number of employees	-0.003	-0.002	0.001	-0.005

	(0.002)	(0.002)	(0.001)	(0.004)
Firm bought fixed assets in past fiscal year	0.00003	0.0000001	0.000*	-0.000
	(0.0001)	(0.0001)	(0.000)	(0.000)
Firm has checking or savings account	-0.018*	-0.015	0.003	-0.027
	(0.011)	(0.012)	(0.007)	(0.018)
Firm has a line of credit or loan	0.007	0.006	-0.001	0.010
	(0.004)	(0.005)	(0.003)	(0.010)
Losses due to breakage/spoilage shipped domestically (% of value of the products	0.0002	-0.001	0.001*	-0.001
	(0.001)	(0.001)	(0.000)	(0.001)
Security costs (% of sales)	-0.0002	-0.0002	0.000	-0.000
	(0.001)	(0.001)	(0.000)	(0.001)
Log of age of firm	0.002	-0.001	-0.001	-0.003
	(0.003)	(0.003)	(0.001)	(0.006)
Female Manager Y/N	0.00001	-0.00001	0.000	-0.000
	(0.000)	(0.000)	(0.000)	(0.000)
Foreign ownership Y/N	0.005	0.005	-0.001	0.010
	(0.006)	(0.007)	(0.007)	(0.012)
Exports 10% or more of sales Y/N	-0.004	-0.002	-0.003	0.005
	(0.007)	(0.007)	(0.004)	(0.015)
Number of years firm was unregistered at start	-0.001	-0.001***	-0.000	-0.002***
	(0.0004)	(0.0003)	(0.000)	(0.001)
Use technology licensed from foreign companies Y/N	-0.002	-0.001	0.010*	-0.013
	(0.006)	(0.006)	(0.006)	(0.012)
Average Monthly Temp for the Year		-0.000	-0.000	0.001
		(0.001)	(0.001)	(0.002)
Square of Average Monthly Temp for the Year		0.0001*	0.000	0.000
		(0.00004)	(0.000)	(0.000)

Constant	0.025	-0.003	-0.027**	-0.115
	(0.031)	(0.029)	(0.011)	(0.082)
Country Fixed effects	No	Yes	Yes	Yes
Region (within country) Fixed Effects	Yes	No	No	No
Sector (2 digit) Fixed Effects	Yes	Yes	Yes	Yes
Number of observations	27,712	24,747	10,257	13,219

Note: Survey weights have been applied to all regressions, using Stata's svy prefix. Linearized Taylor standard errors that account for survey stratification are indicated in parentheses. *** p<0.01, ** p<0.05, * p<0.1

Table 3: Water Shortages and Sales

Y = Log of sales	**Translog (1)**	**Cobb-Douglas (2)**
Log of labor (lnL)	0.769***	0.815***
	(0.022)	(0.036)
Log of capital (replacement value) (lnK)	0.020**	0.036***
	(0.010)	(0.009)
Log of raw materials (costs) (lnM)	0.238***	0.205***
	(0.011)	(0.029)
No. of water shortages per day in a typical month	-0.087**	-0.125***
	(0.037)	(0.044)
Average duration of water shortage	0.002	-0.001
	(0.004)	(0.004)
No. of electrical outages per day in a typical month	0.013	-0.006
	(0.023)	(0.027)
Average duration of electrical outages (hours)	0.001	0.001
	(0.001)	(0.001)
Firm owns or shares a generator Y/N	0.100***	0.156***
	(0.034)	(0.042)
Losses due to breakage/spoilage shipped domestically (% of value of the products	0.0002	-0.007
	(0.003)	(0.005)
Log of age of firm	0.015	0.015
	(0.018)	(0.026)
Foreign ownership Y/N	0.110**	0.198***
	(0.052)	(0.066)
Exports 10% or more of sales Y/N	0.103***	0.189***
	(0.038)	(0.046)

Security costs (% of sales)	-0.011***	-0.019***
	(0.004)	(0.006)
Establishment competes against unregistered or informal firms Y/N	-0.051	-0.127***
	(0.032)	(0.043)
Number of years that firm was unregistered at start	-0.006**	-0.007**
	(0.003)	(0.004)
Formal training Y/N	0.049	0.138***
	(0.031)	(0.038)
lnLlnK	-0.008***	
	(0.001)	
lnLlnM	-0.035***	
	(0.001)	
lnKlnM	0.002**	
	(0.001)	
lnL^2	0.042***	
	(0.002)	
lnM^2	0.032***	
	(0.001)	
lnK^2	0.005***	
	(0.001)	
Constant	3.994***	6.045***
	(0.140)	(0.335)
Region (within country) Fixed Effects	Yes	Yes
Sector (2 digit) Fixed Effects	Yes	Yes
Number of observations	16,847	16,847

Note: Survey weights have been applied to all regressions, using Stata's svy prefix. Linearized Taylor standard errors that account for survey stratification are indicated in parentheses. *** p<0.01, ** p<0.05, * p<0.1

Table 4: Water shortages and Sales by Income Group

Y = Log of sales	**High and Upper Middle Income**	**Low and Lower Middle Income**
	(1)	**(2)**
Log of labor (lnL)	0.884***	0.751***
	(0.126)	(0.026)
Log of capital (replacement value) (lnK)	-0.029	0.023**
	(0.066)	(0.010)
Log of raw materials (costs) (lnM)	0.177***	0.242***
	(0.061)	(0.012)
No of water shortages per day in a typical month	-0.225	-0.082**
	(0.154)	(0.036)
Average duration of water shortage	-0.001	0.004

	(0.005)	(0.005)
No of electrical outages per day in a typical month	-0.031	0.021
	(0.024)	(0.026)
Average duration of electrical outages (hours)	0.001**	-0.000
	(0.000)	(0.002)
lnLxlnK	-0.012**	-0.008***
	(0.006)	(0.001)
lnLxlnM	-0.040***	-0.035***
	(0.007)	(0.002)
lnKxlnM	0.007	0.002**
	(0.007)	(0.001)
$\ln L^2$	0.052***	0.044***
	(0.013)	(0.002)
$\ln M^2$	0.034***	0.033***
	(0.002)	(0.001)
$\ln K^2$	0.005***	0.006***
	(0.002)	(0.001)
Firm owns or shares a generator Y/N	0.014	0.158***
	(0.049)	(0.047)
Losses due to breakage/spoilage shipped domestically (% of value of the products	-0.003	0.002
	(0.007)	(0.004)
Log of age of firm	0.009	0.032
	(0.020)	(0.029)
Foreign ownership Y/N	0.087	0.124
	(0.069)	(0.076)
Exports 10% or more of sales Y/N	0.089*	0.141**
	(0.049)	(0.063)
Security costs (% of sales)	-0.013*	-0.010*
	(0.007)	(0.005)
Establishment competes against unregistered or informal firms Y/N	-0.106***	-0.011
	(0.039)	(0.049)
Number of years firm was unregistered at start	-0.005	-0.010**
	(0.004)	(0.004)
Formal training Y/N	0.016	0.088*
	(0.039)	(0.049)
Constant	7.086***	7.251***
	(0.639)	(0.461)
Region (within country) Fixed Effects	Yes	Yes
Sector (2 digit) Fixed Effects	Yes	Yes
Number of observations	7,909	8,548

Note: Survey weights have been applied to all regressions, using Stata's svy prefix. Linearized Taylor standard errors that account for survey stratification are indicated in parentheses. *** p<0.01, ** p<0.05, * p<0.1

Table 5: Water shortages and sales by water intensity

Y = Log of sales	Water intensive manufacturing sectors (1)	Other manufacturing sectors (1)
Log of labor (lnL)	0.778***	0.762***
	(0.036)	(0.026)
Log of capital (replacement value) (lnK)	0.035**	0.016
	(0.015)	(0.010)
Log of raw materials (costs) (lnM)	0.219***	0.242***
	(0.017)	(0.012)
No of water shortages per day in a typical month	-0.124*	-0.075**
	(0.071)	(0.037)
Average duration of water shortage	0.003	0.001
	(0.005)	(0.004)
No of electrical outages per day in a typical month	-0.014	0.021
	(0.035)	(0.027)
Average duration of electrical outages (hours)	0.002	-0.000
	(0.002)	(0.001)
lnLxlnK	-0.007***	-0.007***
	(0.001)	(0.001)
lnLxlnM	-0.035***	-0.035***
	(0.002)	(0.002)
lnKxlnM	0.002	0.002*
	(0.002)	(0.001)
lnL^2	0.042***	0.042***
	(0.003)	(0.002)
lnM^2	0.033***	0.033***
	(0.002)	(0.001)
lnK^2	0.005***	0.005***
	(0.001)	(0.001)
Firm owns or shares a generator Y/N	0.027	0.141***
	(0.053)	(0.044)
Losses due to breakage/spoilage shipped domestically (% of value of the products	0.004	-0.004
	(0.006)	(0.004)
Log of age of firm	0.024	0.007
	(0.026)	(0.022)
Foreign ownership Y/N	0.121*	0.092
	(0.067)	(0.072)
Exports 10% or more of sales Y/N	0.121**	0.104**
	(0.061)	(0.045)
Security costs (% of sales)	-0.013***	-0.011*
	(0.004)	(0.007)
Establishment competes against unregistered or informal firms Y/N	-0.078*	-0.025

	(0.047)	(0.036)
Number of years firm was unregistered at start	-0.003	-0.005
	(0.004)	(0.004)
Formal training Y/N	0.060	0.071*
	(0.046)	(0.039)
Constant	7.714***	7.741***
	(0.491)	(0.461)
Region (within country) Fixed Effects	Yes	Yes
Sector (2 digit) Fixed Effects	Yes	Yes
Number of observations	5,460	11,387

Note: Survey weights have been applied to all regressions, using Stata's svy prefix. Linearized Taylor standard errors that account for survey stratification are indicated in parentheses. *** p<0.01, ** p<0.05, * p<0.1

Table 6: Magnitude of the Effects of Water Shortages on Firm Performance

Translog production function specification	Loss in sales (US$)	Loss in sales (as % of mean)
All economies:		
1 water incident per day in a typical month	1,052,645	8.7
1 standard deviation increase in water incidents	202,130	1.7
1% increase in water incidents per day	-0.002	
Low and lower middle-income economies:		
1 water incident per day in a typical month	1,082,400	8.2
1 standard deviation increase in water incidents	271,628	2.1
1% increase in water incidents per day	-0.003	

Table A1: Variable Descriptions

Variable	Description	Source
Log of sales	Log of real annual sales in USD	World Bank Enterprise Surveys
Log of labor	Log of total number of full time employees, adjusted for temporary workers	World Bank Enterprise Surveys
Log of capital (replacement value)	Log of cost for establishment to re-purchase all of its machinery	World Bank Enterprise Surveys
Log of raw materials (costs)	Log of cost of raw materials and intermediate goods used in production	World Bank Enterprise Surveys
Number of water shortages per day in a typical month	Number of incidents of water insufficiency per day in a typical month. Water insufficiency is defined as a shortage that affects production. Outages that do not affect production are not counted	World Bank Enterprise Surveys
Average duration of water shortage	Average duration of insufficient water supply in hours	World Bank Enterprise Surveys
Number of electrical outages per day in a typical month	Number of power outages per day in a typical month. Only outages that affect production are counted	World Bank Enterprise Surveys
Average duration of electrical outages (hours)	Average duration of electrical outages in hours	World Bank Enterprise Surveys
Losses due to breakage/spoilage shipped domestically (% of value of the products)	Percentage of value of products the establishment shipped to supply domestic markets lost while in transit because of breakage or spoilage over the last fiscal year	World Bank Enterprise Surveys
Formal training Y/N	Dummy variable that takes the value of 1 if the firm offered formal training programs to its permanent full-time employees, and 0 otherwise	World Bank Enterprise Surveys
Firm owns or shares a generator Y/N	Dummy variable that takes the value of 1 if the firm owns or shares a generator, and 0 otherwise	World Bank Enterprise Surveys
Log of age of firm	Age of firm	World Bank Enterprise Surveys
Foreign ownership Y/N	Dummy variable that takes the value of 1 if the firm has any foreign ownership, and 0 otherwise	World Bank Enterprise Surveys

Expected to give gifts to public officials (to get things done) Y/N	Dummy variable that takes the value of 1 if the firm was expected to give gifts to public officials to get things done	World Bank Enterprise Surveys
Ownership - government/state (%)	Percentage of firm owned by the government	World Bank Enterprise Surveys
Purchased fixed asset Y/N	Dummy variable equal to 1 if the firm purchased fixed assets in the last fiscal year	World Bank Enterprise Surveys
Establishment has a line of credit or loan at this time Y/N	Dummy variable equal to 1 if the firm has a loan or line of credit at the time of survey	World Bank Enterprise Surveys
Exports 10% or more of sales Y/N	Dummy variable that takes the value of 1 if the firm exports at least 10 % or more of its sales, and 0 otherwise	World Bank Enterprise Surveys
Security costs (% of sales)	Percentage of establishment's total annual sales that was paid for security	World Bank Enterprise Surveys
Establishment competes against unregistered or informal firms Y/N	Dummy variable that takes the value of 1 if the establishment competes against unregistered or informal firms, 0 otherwise	World Bank Enterprise Surveys
Number of years that firm was unregistered at start	Difference between the year the firm started operations, and when the firm was formally registered. Variable takes a value of zero if firm was registered when they started operations	World Bank Enterprise Surveys
Bribery depth	% of public transactions where a gift or informal payment was requested	World Bank Enterprise Surveys
Bribery incidence	Firms experiencing at least one bribe payment request Y/N	World Bank Enterprise Surveys
Informal payment/gift requested for water connection Y/N	Dummy variable that takes the value of 1 if the firm applied for a water connection over the last 2 years before the survey and an informal payment or gift was expected or requested	World Bank Enterprise Surveys
Proportion of public transactions (excluding water) where a gift or informal payment required	Proportion of public transactions (excluding water) that required a gift or informal payment for firms that applied for a water connection in the last 2 years	World Bank Enterprise Surveys
Firm experienced at least one public transactions (excluding water) where a gift or informal payment required	Dummy variable that takes the value of 1 if the firm was asked for an informal payment or gift was expected or requested for any public transaction excluding water (this is only for firms that applied for a water connection)	World Bank Enterprise Surveys

Wait for water connection (days)	Number of days between application for a water connection and the receipt of the service	World Bank Enterprise Surveys
Establishment has checking or savings account Y/N	Dummy variable that takes the value of 1 if the firm has a checking or savings account at this time	World Bank Enterprise Surveys
Female manager Y/N	Dummy variable that takes the value of 1 if the top manager of the firm is female	World Bank Enterprise Surveys
Use technology licensed from foreign companies Y/N	Dummy variable that takes the value of 1 if the firm uses technology licensed from foreign companies	World Bank Enterprise Surveys
Average historical temperature 1900-2014	Gridded dataset that contains monthly observations of precipitation and average temperature at the 0.5 degree grid cell level. Data transformed into average monthly temperature, and total precipitation (mm), per year, for each grid cell.	Matsuura and Willmott, (2012a)
Average historical precipitation 1900-2014	Gridded dataset that contains monthly observations of precipitation and average temperature at the 0.5 degree grid cell level. Data transformed into average monthly temperature, and total precipitation (mm), per year, for each grid cell. Precipitation shocks defined based on the long run mean and standard deviation of annual precipitation for each grid cell from 1900-2014.	Matsuura and Willmott, (2012b)
Standardized Precipitation Index (SPI)	Gamma distribution fitted to precipitation data to correct for the fact that precipitation data is not normally distributed.	Computed from Matsuura and Willmott, (2012b) precipitation data.

Table A2: Country Composition

Country	Year	Country	Year
Afghanistan	2014	Madagascar	2013
Albania	2013	Malawi	2014

Angola	2010	Malaysia	2015
Argentina	2010	Mali	2010
Armenia	2013	Mauritania	2014
Azerbaijan	2013	Mauritius	2009
Bangladesh	2013	Mexico	2010
Belarus	2013	Moldova	2013
Bhutan	2015	Mongolia	2013
Bolivia	2010	Montenegro	2013
Bosnia and Herzegovina	2013	Morocco	2013
Botswana	2010	Mozambique	2007
Brazil	2009	Myanmar	2014
Bulgaria	2013	Namibia	2014
Burkina Faso	2009	Nepal	2013
Burundi	2014	Nicaragua	2010
Cambodia	2016	Nigeria	2014
Cameroon	2009	Pakistan	2013
Chile	2010	Panama	2010
China	2012	Papua New Guinea	2015
Colombia	2010	Paraguay	2010
Costa Rica	2010	Peru	2010
Croatia	2013	Philippines	2015
Czech Republic	2013	Poland	2013
Côte d’Ivoire	2009	Romania	2013
Democratic Republic of Congo	2013	Russian Federation	2012
Djibouti	2013	Senegal	2014
Dominican Republic	2010	Serbia	2013

Ecuador	2010
Egypt, Arab Rep.	2013
El Salvador	2010
Ethiopia	2015
FYR Macedonia	2013
Georgia	2013
Ghana	2013
Guatemala	2010
Honduras	2010
Hungary	2013
India	2014
Indonesia	2015
Iraq	2011
Israel	2013
Jamaica	2010
Jordan	2013
Kazakhstan	2013
Kenya	2013
Kosovo	2013
Kyrgyz Republic	2013
Lao PDR	2016
Latvia	2013
Lebanon	2013
Lithuania	2013
Slovak Republic	2013
Slovenia	2013
Solomon Islands	2015
South Africa	2007
South Sudan	2014
Sri Lanka	2011
Sudan	2014
Tajikistan	2013
Tanzania	2013
Thailand	2016
Timor-Leste	2015
Trinidad and Tobago	2010
Tunisia	2013
Turkey	2013
Uganda	2013
Ukraine	2013
Uruguay	2010
Uzbekistan	2013
Venezuela, RB	2010
Vietnam	2015
West Bank and Gaza	2013
Yemen, Rep.	2013
Zambia	2013

Table A3: Robustness Checks – Interacting Water and Electricity Outages, and Including Additional Control Variables

Y = Log of Sales	**Water x Electricity (1)**	**Additional variables: Finance, Corruption (2)**
Log of labor (lnL)	0.769***	0.759***
	(0.022)	(0.023)
Log of capital (replacement value) (lnK)	0.020**	0.017*
	(0.010)	(0.010)
Log of raw materials (costs) (lnM)	0.238***	0.238***
	(0.011)	(0.011)
No. of water shortages per day in a typical month	-0.143*	-0.096**
	(0.073)	(0.045)
Water incidents x electricity incidents	0.013	
	(0.010)	
Water duration x electricity duration	-0.000	
	(0.000)	
Expected to give gifts to public officials (to get things done) Y/N		0.018
		(0.048)
Ownership - government/state (%)		0.003
		(0.002)
Purchased fixed asset Y/N		0.032
		(0.030)
Establishment has a line of credit or loan at this time		0.069**
		(0.034)
Average duration of water shortage	0.003	0.002
	(0.004)	(0.005)
No. of electrical outages per day in a typical month	0.012	-0.002
	(0.023)	(0.024)
Average duration of electrical outages (hours)	0.001	0.001
	(0.001)	(0.001)
lnLlnK	-0.008***	-0.007***
	(0.001)	(0.001)
lnLlnM	-0.035***	-0.035***
	(0.001)	(0.001)
lnKlnM	0.002**	0.002**
	(0.001)	(0.001)
lnL^2	0.042***	0.042***
	(0.002)	(0.002)

lnM^2	0.032***	0.033***
	(0.001)	(0.001)
lnK^2	0.005***	0.005***
	(0.001)	(0.001)
Firm owns or shares a generator Y/N	0.100***	0.079**
	(0.034)	(0.036)
Losses due to breakage/spoilage shipped domestically (% of value of the products	0.000	-0.000
	(0.003)	(0.004)
Log of age of firm	0.015	0.009
	(0.018)	(0.018)
Foreign ownership Y/N	0.109**	0.106*
	(0.052)	(0.056)
Exports 10% or more of sales Y/N	0.103***	0.122***
	(0.038)	(0.041)
Security costs (% of sales)	-0.011***	-0.011**
	(0.004)	(0.004)
Establishment competes against unregistered or informal firms Y/N	-0.052	-0.051
	(0.032)	(0.034)
No. of years that firm was unregistered at start	-0.006**	-0.007**
	(0.003)	(0.003)
Formal training Y/N	0.049	0.046
	(0.031)	(0.033)
Constant	7.678***	4.015***
	(0.398)	(0.150)
Region (within country) Fixed Effects	Yes	Yes
Sector (2 digit) Fixed Effects	Yes	Yes
Number of observations	16,847	15,469

Note: Survey weights have been applied to all regressions, using Stata's svy prefix. Linearized Taylor standard errors that account for survey stratification are indicated in parentheses. *** p<0.01, ** p<0.05, * p<0.1

Table A4: Robustness Checks – Stochastic Frontier Analysis

Log of Sales	**Frontier (1)**	**Usigma (2)**
Log of labor (lnL)	0.874***	
	(0.035)	
Log of capital (replacement value) (lnK)	0.037***	
	(0.008)	

Log of raw materials (costs) (lnM)	0.203***	
	(0.026)	
No. of water shortages per day in a typical month		0.311***
		(0.110)
Average duration of water shortage		0.015
		(0.011)
No. of electrical outages per day in a typical month		0.023
		(0.078)
Average duration of electrical outages (hours)		0.001
		(0.003)
Firm owns or shares a generator Y/N		-0.001
		(0.236)
Losses due to breakage/spoilage shipped domestically (% of value of the products		0.026**
		(0.011)
Log of age of firm		-0.051
		(0.120)
Foreign ownership Y/N		-0.046
		(0.311)
Exports 10% or more of sales Y/N		-0.830***
		(0.291)
Security costs (% of sales)		0.077***
		(0.024)
Establishment competes against unregistered or informal firms Y/N		0.335*
		(0.186)
No. of years that firm was unregistered at start		0.017
		(0.015)
Formal training Y/N		-0.545***
		(0.185)
Constant	12.300***	-1.807***
	(0.431)	(0.657)
Vsigma	-0.463***	
	(0.104)	
Region (within country) Fixed Effects	Yes	No
Sector (2 digit) Fixed Effects	Yes	No
Number of observations	16,847	

Note: Survey weights have been applied to all regressions, using Stata's svy prefix. Linearized Taylor standard errors that account for survey stratification are indicated in parentheses. *** p<0.01, ** p<0.05, * p<0.1

Table A5: Robustness Checks – Water Shortages and Sales, using Logs of Water Infrastructure Variables

Y = Log of sales	**Translog**	**Cobb-Douglas**
	(1)	**(2)**
Log of labor (lnL)	0.769***	0.815***
	(0.022)	(0.036)
Log of capital (replacement value) (lnK)	0.020**	0.036***
	(0.010)	(0.009)
Log of raw materials (costs) (lnM)	0.238***	0.205***
	(0.011)	(0.029)
Log of no of water shortages per day in a typical month	-0.257*	-0.386**
	(0.135)	(0.155)
Log of average duration of water shortage	0.027	0.013
	(0.034)	(0.037)
Log of no of electrical outages per day in a typical month	0.037	-0.042
	(0.067)	(0.091)
Log of average duration of electrical outages (hours)	-0.006	0.027
	(0.022)	(0.040)
Firm owns or shares a generator Y/N	0.101***	0.155***
	(0.034)	(0.043)
Losses due to breakage/spoilage shipped domestically (% of value of the products	0.000	-0.007
	(0.003)	(0.005)
Log of age of firm	0.015	0.015
	(0.018)	(0.027)
Foreign ownership Y/N	0.109**	0.201***
	(0.052)	(0.066)
Exports 10% or more of sales Y/N	0.103***	0.187***
	(0.038)	(0.046)
Security costs (% of sales)	-0.011***	-0.019***
	(0.004)	(0.006)
Establishment competes against unregistered or informal firms Y/N	-0.051	-0.128***
	(0.032)	(0.044)
No. of years that firm was unregistered at start	-0.006**	-0.007**
	(0.003)	(0.004)
Formal training Y/N	0.049	0.136***

	(0.031)	(0.038)
lnLlnK	-0.008***	
	(0.001)	
lnLlnM	-0.035***	
	(0.001)	
lnKlnM	0.002**	
	(0.001)	
lnL^2	0.042***	
	(0.002)	
lnM^2	0.032***	
	(0.001)	
lnK^2	0.005***	
	(0.001)	
Constant	3.998***	6.035***
	(0.139)	(0.327)
Region (within country) Fixed Effects	Yes	Yes
Sector (2 digit) Fixed Effects	Yes	Yes
Number of observations	16,847	16,847

Note: Survey weights have been applied to all regressions, using Stata's svy prefix. Linearized Taylor standard errors that account for survey stratification are indicated in parentheses. *** p<0.01, ** p<0.05, * p<0.1