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Does Drought Increase Carbon Emissions? Evidence from Southwestern China

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Abstract

This study estimates the impact of the 2009/2010 drought in southwestern China on economic activities and CO_2 emissions. We focus on the economic outcomes of the power and energy-intensive sectors to investigate the substitution between hydropower and thermal power during this extreme drought. Panel data for 97,387 firms from 2006 to 2013 are used to examine the responses of firms to this extreme climatic event. We find that severe drought reduces hydropower generation, as well as the economic outputs of energy-intensive sectors, while it increases the power generated by coal-fired power plants. As a result, the net emissions of carbon dioxide between 2009 and 2013 increased by 443,425 tons. The findings suggest that climate disasters may increase carbon emissions, thereby posing a threat to further climate change.

JEL classification: D22; L94; Q25; Q54

Keywords: Extreme drought; Power and energy-intensive sectors; Hydropower; Thermal power; CO_2 emissions

1 Introduction

Attaining water and energy security is a significant challenge for every country. This is particularly true for a country such as China, which has an uneven distribution of resources and an obvious geographical mismatch between demand and supply. For instance, the northern provinces hold only 16% of the water resources, but accounted for more than 60% of the national amount of coal, crude oil, and electricity production in 2015 (Lin and Chen, 2017). Furthermore, hydropower resources in the western provinces account for 81.46% of the national total, while over half of the net electricity consumption is made by the eastern coastal provinces (Wei, 2014; Li et al., 2015). However, China's power demand is expected to increase by 65% by 2030 compared to 2013 (IRENA, 2016) and nine 10-GW coal-power bases will be built in arid regions according to the Energy Development Strategy Action Plan 2014–2020, which will further increase the water scarcity (Shang et al., 2016).

As a result, the government has proposed in the 13th Five-Year Plan dual control actions that promote energy and water conservation and efforts such as energy structure adjustment and water utilization have been directed toward the development of renewable energy. However, climate change poses immediate risks to the fresh water supply for the production of electricity, as droughts are becoming more frequent and severe (Eyer and Wichman, 2018). The industrial sector is the dominant energy consumer in China, accounting for 87% of the total national consumption in 2013, of which the secondary industry consumes 84% (Wei, 2014). Therefore, how and to what extent climate change affects economic activities directly or indirectly through the water–energy nexus is becoming increasingly uncertain.

This study focuses on the impact of the southwestern drought in 2009/2010, referred to as the most severe drought event over the past century in China. During this drought, precipitation decreased by 90% and the summer growing season was 1.5 °C hotter than normal (Zhang et al., 2012). The drought began in October 2009 and its impact lasted more than a year. It encompassed the Yunnan, Guizhou, and Guanxi provinces, as well as parts of Sichuan Province and Chongqing, affecting 60 million people and 6.5 million hectares of agricultural land. As reported in the 2011 China Electric Power Yearbook, in 2010, the hydropower generation of Guizhou and Guangxi decreased by 14% and 25%, respectively, compared to 2009 because of the drought. Moreover, the drought reduced the operating hours of hydropower considerably and the electricity transmitted to Guangdong province by 6 billion kWh by the end of 2010. Some provinces and cities had to implement power rationing to deal with the resulting long-term power shortages.

The southwestern drought thus provides an opportunity to examine the impact of persistent drought on the economic activities of the power and energy-intensive sectors. To this end, we develop three hypotheses regarding the water–energy nexus under climate change. First, we assume that extreme drought affects the power and energy-intensive sectors more than the other sectors because of the damage to hydropower. Second, the overall power sector may suffer less than energy-intensive sectors because the drought will substitute hydropower with thermal power generation in the energy mix. Third, the southwest drought likely increases carbon emissions due to this dramatic shift in the energy mix.

Recently, the water–energy nexus has received significant attention from researchers. Various studies on the tradeoffs between water and energy have been undertaken, also incorporating the future impacts of climate change. Through simulation models and life-cycle assessments, researchers have found that water-saving technologies, the energy mix, and coal and water consumption control policies can reduce water vulnerabilities in the power industry under climate change (Koch and Vögele, 2009; Zheng et al., 2016; Zhang et al., 2018; Shang et al., 2018). For instance, Zheng et al. (2016) examine the regional water vulnerability of thermal power using a vulnerability index, and find that the construction of mine-mouth power plants may aggravate the existing vulnerability and turn non-vulnerable regions into vulnerable ones. Other researchers explore the relationship between the water–energy nexus and the industrial sector. Gu et al. (2016) use input–output analysis to test the effects of energy conservation policy on the water saving in industrial sectors. They suggest that technology adoption in energy-intensive industries can lead to a substantial water saving effect. Further, Su et al. (2018) assess future drought losses under a global temperature increase and predict a considerable GDP reduction in the absence of climate change mitigation. Understanding the water–energy nexus in industrial sectors is crucial in exploring measures for adapting to climate change.

A growing body of literature focuses on the effects of weather fluctuations on the water–energy nexus and economic activities. For example, Eyer and Wichman (2018) investigate the effects of water scarcity on the US energy mix using plant-level data and the Palmer Drought Severity Index; they indicate that drought is likely to decrease hydroelectric generation and increase CO_2 emissions and local pollutants in the US. McDermott and Nilsen (2014) provide empirical evidence from Germany that electricity prices are significantly affected by both falling river levels and higher river temperatures. Furthermore, Zhang et al. (2018) and Chen and Yang (2019) estimate the responses of industrial output to temperature changes in China. Specifically, Zhang et al. (2018) find a non-linear relationship between temperature and total factor productivity and that high temperature has detrimental effects on output. Chen and Yang (2019) conclude that adaptation to global warming may have been undertaken in high-temperature regions. In terms of empirical analysis on drought events, most studies focus on their impacts on agriculture, ecosystems, or variations in drought patterns (Simelton et al., 2009; Zhang et al., 2012; Alauddin et al., 2014; Wang et al., 2015; Parida et al., 2018).

As such, few researchers note the association between persistent drought and the outputs of the power and energy-intensive sectors. Moreover, it is not clear how firms respond to the long-term water and power shortages due to drought and the subsequent environmental consequences. Our study fills this literature gap by estimating the relationship between the water–energy nexus and economic activities in the context of persistent drought. We use panel data for 97,387 firms from 2006 to 2013 to examine the impact of extreme drought on energy-intensive industries and power production in regions with a high hydropower share. Second, we investigate the heterogeneous effects of long-term water shortages on firms' responses across industries, regions, and years using difference-in-difference-in-differences (DDD) models. Finally, we estimate the environmental impact of the southwest drought by calculating the net carbon emissions of industrial sectors.

The remainder of this paper is organized as follows. Section 2 overviews China's western development strategy and the southwestern drought. Section 3 describes the treatment design and estimation strategy. Section 4 explains the data and sampling procedure. Section 5 presents the empirical results. Section 6 discusses the environmental consequences of drought on industrial sectors. Conclusions based on our findings are presented in the final section.

2 Background

Severe drought is one of the most devastating natural disasters in China. Drought-affected areas have significantly increased and extreme droughts have occurred frequently since 2000 (Xu et al., 2015). Extreme droughts affecting more than 10 million people only occurred five times between 1983 and 1999; however, the number of occurrence doubled between 2000 and 2016. Particularly, the extreme droughts in 2010 and 2011 caused severe water shortages in the affected regions. Furthermore, the growing water scarcity and competition for water supply have transferred the impact of droughts to distant cities. Although an extreme drought does not affect the industrial sector directly or immediately, it causes long-term water shortages, high temperatures, and eventually lowers productivity. Over the past 10 years, annual industrial losses from drought have exceeded 230 billion yuan (Zhang et al., 2012). As climate change is predicted to further decrease precipitation and increase drought risk, more frequent drought events and of longer duration are projected in the southwestern river basins (Xu et al., 2015; Huang et al., 2018).

Although the southwestern provinces of China are water-rich areas, they are also vulnerable to extreme droughts. The southwestern region[1] holds most of the hydropower resources in China, comprising approximately 67% of the total national exploitable hydropower resources (Liu et al., 2018). China has promoted hydropower development in the southwestern region and has implemented the Western Development and the West–East Electricity Transmission Project in 2000. This project is designed to optimize the distribution of China's resources and electric power structure to ease electricity shortages in developed regions by exploiting the resources in the southwestern region (Ming et al., 2013). The southern route of the West–East Power Transmission project transmits Guizhou's thermal power and the hydropower of Yunnan, Guizhou, and Guangxi to the Pearl River Delta (Guangdong, Hong Kong, and Macau). In 2010, both the transmission capacity and electricity amount of the southern route were 10 times higher than those of 2000, with the maximum power capacity of western electricity to Guangdong accounting for 27% of its maximum load and 30% for Guangxi (Ming et al., 2013). Moreover, as a cost-effective clean energy, hydropower plays a prominent role in China's 12th and 13th Five-Year Plans to achieve the commitment to reduce greenhouse gas (GHG) emissions.

[Table 1]

The development of hydropower may make the southwestern regions more vulnerable to drought for several reasons as follows. First, various supporting policies and cheap electric hydropower are attractive to firms in energy- and water-intensive industries. Pollution-intensive industries are concentrated in the southwestern region, which may cause water scarcity due to water quality deterioration. Second, industrial agglomerations reliant on hydropower are more easily affected by drought-related water scarcity. According to Table 1, the share of the power and energy-intensive firms in the southwestern region is 8% higher than that in other regions. Third, climate change will increase drought risk, meaning more thermal power plants are needed as alternatives for power generation, which will further stress the water–energy nexus in this region. Finally, local policies balancing both power interests and environmental concerns are not sufficient, which can have a significant influence on water exploitation decisions (Kosnik, 2010). In the southwestern region, the annual investment in water saving is less than half of that in other regions, and the water resource fee is also significantly lower (MOHURD, 2006–2013).

3 Estimation Strategy

3.1 Treatment Indicators

To examine the impact of drought on industrial activities and the energy mix, we propose three treatment indicators for the DDD analysis. We use the first treatment variable, *Drought*, to capture the effects of being a province hit by the southwestern drought. The second treatment variable, *Post*, indicates the period after the drought, and the third treatment variable, *Energy*, captures the effect of being a firm in a power or energy-intensive sector. We interact these three treatment variables to identify the effect of being a power firm or an energy-intensive one in a drought-affected area.

[Figure 1]

Figure 1 shows the geographical division of the treatment and control groups. The treatment group includes five southwestern provinces: Sichuan, Chongqing, Guizhou, Yunnan, and Guangxi. Regarding the control group, our primary concern are the impacts of other severe droughts between 2006 and 2013. As mentioned in Section 2, two extreme droughts occurred during our study period, that is, the southwestern drought and the 2011 drought in northern China, both of which caused significant damage and water shortages. However, the 2011 drought affected most wheat-producing regions and, thus, its influence on the industrial sector was limited. To control for the impact of the 2011 drought, we divide the control group into two groups to distinguish the affected provinces. We use both groups as controls in the baseline regression, and then use only group 1 as a control for the robustness check. We keep Tibet in control group 2 because only 1% of firms are located in Tibet. According to the EM-DAT database, the southwestern drought started in October 2009 and, therefore, we set 2008 as the baseline year.

3.2 Industrial Outcome Model

We estimate the effect of the southwestern drought on the industrial outcomes of the power and energy-intensive sectors using the following equation:

$$LogY_{ijt} = \sum_{e \in E \in n} \beta^e (Drought_j \times Post_t \times Energy_i^e) + \delta_{jt} + \theta_{nt} + \lambda_{nj} + \mu_i + \eta_t + \varepsilon_{ijt} \quad (1)$$

where $LogY_{ijt}$ is the logarithm of the industrial outcome of firm i in province j in year t, and includes two outcome measures: the firm's output and revenue. $Drought_j$ is a province dummy that equals 1 if province j is located in the southwest. $Post_t$ is a dummy variable that indicates the post-drought period; it equals 1 if t>2008, and 0 otherwise. $Energy_i^e$ is a dummy indicator for each firm's industry type e, which is included in the two-digit industry E (power and energy-intensive sectors) (see Table A1 in the Appendix for detailed information on the industry classification codes). n represents all two-digit industries, n=06, $\cdots$, 46. We include δ_{jt}, θ_{nt}, and λ_{nj} to capture the effects of unobservable regional policy, industrial regulation, and economic shock in a given province and year, industry and year, and industry and province. Firm fixed effect μ_i controls for unobservable time-invariant firm characteristics. η_t is a year effect common to all firms in period t, which control for national energy policy and environmental regulation over time. ε_{ijt} denotes the error item. We allow for correlation within two-digit industries and spatial correlation across industries within a given province and year by clustering the standard errors.

Our interest is in the parameter of the triple difference term, β^e. We examine the separate effects of drought on energy-intensive and the power sectors. In our analysis, energy-intensive sectors are defined as five two-digit energy-intensive manufacturing industries (see Table A1 in the Appendix for details). The power sector in one region could be less affected than the energy-intensive sectors during a drought, depending on the energy mix of that region. If the alternative electricity resource is sufficient, the power sector can maintain electricity production to meet urgent needs. The power sector is comprised of five four-digit electric power industries, including the hydropower and thermal power industries. We combine the nuclear power and wind power industries with other electric power industries because of the limited size of the latter. We further investigate the heterogeneous effects of drought on the hydropower, thermal power, and other power industries. We assume $\beta^{power} > \beta^{energy-intensive}$; $\beta^{hydro} < 0$; $\beta^{thermal} > 0$; $\beta^{other} > 0$.

Furthermore, to examine how treatment effects vary across drought-affected provinces and years, we use equation (2) to estimate DDD models with multiple provinces or time periods:

$$LogY_{ijt} = \sum_{j=1}^{5} \sum_{e \in E \in n} \beta^e (Drought_j \times Post_t \times Energy_i^e) + \delta_{jt} + \theta_{nt} + \lambda_{nj} + \mu_i + \eta_t + \varepsilon_{ijt} \quad (2)$$

where j=1, $\cdots$, 5 for Guangxi, Chongqing, Sichuan, Guizhou, and Yunnan, respectively. For the estimation considering multiple time periods, we replace $\sum_{j=1}^{5}$ with $\sum_{t=-2}^{5}$, where t=-2, -1, 1, 2, 3, 4, 5, indicating the 2 years befpre the baseline—2006, 2007—and the 5 years after the baseline—2009 to 2013. For these two analyses, apart from output and revenue, two more dependent variables are added, namely, employment and assets. Employment indicates the average annual number of employees, thus indicating the scale and growth potential of a firm. Assets indicate the firm's total assets, including fixed and current assets.

4 Data

We use several data sources for the empirical estimations. The main data source is the National Bureau of Statistics' (NBS) Annual Industrial Firm Survey. We construct a balanced firm-level panel dataset from 2006 to 2013 to estimate the industrial outcome model. The dataset includes 97,387 firms and 779,096 observations from 41 two-digit industries. Drought data were obtained from the EM-DAT database, which contains data on the occurrence, location, and effects of severe droughts in China. We utilize this database to identify other provinces affected by severe droughts other than the southwestern drought during our study period.

The NBS industrial firm survey covers all industrial enterprises above a designated size from 1998 to 2013. The definition of designated size changed twice, in 2007 and 2011. From 1996 to 2007, the survey covered all state-owned enterprises (SOEs) and other enterprises with a main annual business revenue of 5 million yuan or more. From 2007 to 2010, SOEs under this designated size were excluded. Then, the threshold for an industrial enterprise increased to 20 million yuan from January 2011. Because we use panel data from 2006 to 2013, the firms in our sample are industrial enterprises with a main annual business revenue of 20 million yuan or more.

Several variables can be used to identify a firm: unique matching identification (ID), firm ID, administrative code, industry code, firm name and legal representative. Each firm has a firm ID, but firms can change their IDs as a result of restructuring, acquisition, or mergers (Zhang et al., 2018). We use the unique matching ID to merge firm data over time. Furthermore, to ensure that the matching ID does not change similarly to the firm ID, we follow previous studies to match firms based on administrative codes and firm names, as well for double-checking (Zhang et al., 2018; Chen and Yang, 2019). Our dataset includes three secondary industry sectors, namely mining and quarrying, manufacturing, and utilities, and 41 two-digit industries, which is consistent with the China Industry Classification System GB/T4754-2011. Each firm is attributed a four-digit China Standard Industrial Classification (CSIC) code, which is used to identify its industry sector.

Most firms in energy-intensive sectors are located in the eastern coastal provinces in the control group and in Sichuan Province in the treatment group. Further, the agglomeration of firms in energy-intensive sectors is highly power-driven. Although nuclear power and renewable energy have developed rapidly over the last decade, thermal power and hydropower still dominate the energy mix. Large thermal power firms are concentrated in the eastern coastal region and central China, while around half of the large hydropower firms are in the southwestern region.

An inherent weakness of the dataset is the large amount of missing data in the surveys after 2007. The survey in 2010 contains only data on revenue, employment, and total assets. Moreover, we were able to collect data on the annual average number of employees before 2010 but, after 2010, only the total number of employees at the end of the survey year is available. Therefore, we collect seven years of data on output and eight years of data on revenue, employment, and total assets as dependent variables. We drop unreasonable observation, such as negative values for our dependent variables and firm age. The rest of the data are used to compile an eight-year balanced panel dataset for the analysis.

According to the summary statistics in Table 1, the average share of power and energy-intensive firms is 18.8% in the control group, among which 16.8% are energy-intensive firms and 2% are power firms. In the treatment group, the average share of firms in energy-intensive sectors is 22% and that in the power sector is 7%. The southwestern region has less power and energy-intensive firms in absolute value, but their shares are larger. Moreover, the share of hydropower firms in the treatment group is more than 10 times larger than that in the control group. According to the results, 40% of power firms are hydropower firms in the treatment group, compared to 10% in the control group.

5 Results

5.1 Baseline Results

[Table 2]

We report the baseline regression results in Table 2 by estimating equation (1) for the full sample and including control groups 1 and 2. The estimated effects of the southwestern drought on the log output and log revenue are reported. We control for province and year fixed effects, province and two-digit industry fixed effects, year and two-digit industry fixed effects, and year fixed effects in all the models. Firm fixed effects are included in models (2)–(4) and (6)–(8).

The results in columns (1)–(4) show that the southwestern drought had a negative but insignificant impact on the output of the power and energy-intensive sectors, while the effect on energy-intensive firms is negative and significant at the 5% level. Conversely, the drought had a positive but insignificant effect on the power sector. Moreover, the southwestern drought had heterogeneous effects on four-digit electric power industries: it reduced the output of hydropower firms by 20.1%, but increased the output of thermal power firms and other power firms by 34.6% and 52.3%, respectively. Columns (5)–(8) present the estimated effects on the logged revenue of firms in the power and energy-intensive sectors. Overall, the power and energy-intensive sectors bear a significant loss, of 5.9%. The revenue of energy-intensive sectors decreased by 7.6%, while the effect on the revenue of the power sector is negative but insignificant. The revenue loss for hydropower firms was 21.6%, larger than the change in the output, whereas the other power firms experienced an increase of 21.3% in revenue. Interestingly, the southwestern drought is associated with a reduction of 8.8% in revenue of thermal power firms, despite the increase in output. Several reasons could explain this difference. First, the positive impact on revenue did not last, which we will investigate later with multiple-period regressions. Second, electricity may have been primarily provided for disaster relief during the drought, which may have led to a decrease in the sales of thermal power firms. Finally, the energy market status, such as seasonal changes in coal prices and the lack of coal reserves, could also influence revenue.

5.2 Robustness Check

Although the southwestern drought can be regarded as a random shock, we are concerned about the potential self-selection bias in our sample. As mentioned above, the three most developed economic zones[2] in central and eastern coastal China have always been the first options for firm locations, especially for large private firms. Meanwhile, the West Triangle Economic Zone in the southwest is still being designed as a component of the Western Development policy. We have reasons to believe that the firms that move to or start from southwestern China might have different firm-level characteristics compared to the firms in other regions. For instance, southwestern China may have more SOEs to provide additional job opportunities.

We use the nearest-neighbor matching method to address this issue. Three firm characteristics are selected as covariate variables for matching: firm age, industry type, and ownership type. We keep the firms from the baseline year (2008) and employ one-to-one nearest neighbor matching with replacement using a 0.05 caliper to reduce the likelihood of poor matches. Additionally, balancing tests after matching are performed to check whether firms in the treatment and control groups are well balanced. There is no statistically significant difference between the treated and control means after matching, and the bias of all covariates is reduced to below 10% (see Table A2 in the Appendix for the balancing test results). Only 19 firms in the control group have been dropped and the estimation results after matching are similar to the baseline results.

[Table 3]

We run another estimation to control for the possible impact of the extreme drought in 2011, and the estimated effects are reported in Table 3. The results remain robust when we drop control group 2, which implies that the influence of the 2011 drought is too small to be considered, and our results are robust across the different samples. Consequently, the southwestern drought is associated with an average decrease of 7.8% in output and 7.6% in revenue for the energy-intensive firms in the drought-affected regions, that is, an average of 11.7 million yuan and 12.7 million yuan[3] per firm, respectively. In the power sector, hydropower firms sustained the most severe damage, and output and revenue were reduced, on average, by 20.1% and 21.6%, or 16.8 million yuan and 18.1 million yuan, respectively.[4] By contrast, the drought increased the output of thermal power firms by 34.6%, but decreased revenue by 8.8%, that is, a 224.5 million yuan increase in output and 57.4 million yuan decrease in revenue [5]. As for other power firms, drought is associated with a significant increase in both output and revenue, although the absolute size of the increase is not as large because of their low share in the total output.

In conclusion, the effect of the drought on the power and energy-intensive sectors is negative, while the effect on the power sector is insignificant because of the substitution between the hydropower and other power sectors. Our findings are consistent with those of Eyer and Wichman (2018) in that water scarcity will likely shift the U.S. energy mix from relatively water-intensive generation towards alternative sources. Further, a devastating drought like the southwestern drought induces more thermal power production.

5.3 Heterogeneity Across Firm Ownership Type

To investigate the heterogeneous impacts of drought on firms with different ownership types, we collect information on firms' ownership types to perform more detailed estimations. There are six firm ownership types for firms: SOEs; COEs; private firms; foreign firms; Hong Kong, Macao, and Taiwan firms; and mixed-ownership firms (Chen and Yang, 2019). Hong Kong, Macao, and Taiwan firms are considered foreign firms according to the NBS definition.

Our analysis does not include mixed-ownership firms owing to their lack of clarity.

Several studies have shown that different firm types (by ownership type) tend to behave differently to external shocks. For instance, Zhang et al. (2010) investigate how ownership affects corporate philanthropic responses to the 2008 Sichuan Earthquake, and find that non-SOEs are more strategically motivated and economically driven to engage in philanthropic responses than SOEs. Cai et al. (2016) study heterogeneity among different firms in response to environmental regulations. They find that private firms are cost sensitive and less environmentally conscious than SOEs and foreign firms, and take more action to avoid stringent policies. Zhang et al. (2018) examine the heterogeneity in temperature effects across firm ownership types, and suggest that the effects of high temperatures on output may be stronger for private firms than for SOEs because of the weaker enforcement of labor regulations in the former. Furthermore, the magnitude of the temperature effect is linked to the sample share of each ownership type.

We examine the effects of the southwestern drought on the outputs and revenues of SOEs, COEs, privates firms, and foreign firms to infer their possible responses to the drought event. The share of each type in the balanced firm sample is 6.88%, 4.55%, 66.07%, and 19.52%, respectively. In the control group, the respective shares are 6.22%, 4.49%, 65.80%, and 20.57%. In the treatment group, the shares are 15.58%, 5.36%, 69.65%, and 5.53%, respectively. However, SOEs comprise the largest share in the power sector of the treatment group: 56.41% for hydropower and 85.83% for thermal power.

[Table 4]

The results are presented in Table 4. Columns (1)–(8) show the estimated effects of the southwestern drought on output and revenue. The drought reduced the output and revenue of the SOEs in energy-intensive sectors by 12.1% and 10.4%, respectively, but only the effect on output is statistically significant at the 10% level. Private firms experienced less damage in terms of output and revenue, although they comprise the largest share in the sample. Conversely, foreign firms bore the largest loss according to columns (7) and (8), despite their share being the smallest. As implied in prior studies, private firms are more cost-sensitive and profit-driven and, thus, they may respond negatively to power rationing during drought. Another possible reason is that many private firms are located in urban areas that suffered less damage from the drought. Foreign firms sustained the worst damage, although their sample share was the smallest in the treatment group. This is because they are more likely to follow the power rationing policy and do not have enough capacity and resources to deal with extreme drought, which may lead to significant production damage. In the hydropower industry, both

SOEs and COEs (columns (1) and (2)) incurred large losses, of more than 20%, in output and revenue. Meanwhile, the results for thermal power firms in columns (5) and (6) show that the drought decreased the revenue of SOEs by 12.2%, but increased the revenue of COEs by 24.5%. Compared to private and foreign firms, SOEs are less cost-sensitive and more locally based (Cai, 2016). As such, they may play the role of a safety net during drought to adjust the energy market rather than make profit. COEs are also locally based, but are more flexible and have a less significant social purpose. Similar to the energy-intensive sectors, private firms in the hydropower industry experienced the least loss, but benefitted most from the thermal power industry, whereas foreign firms incurred the largest loss in almost all industries.

5.4 Effects on Power Production by Province and Year

The effects of drought vary across provinces, and firms in the worst affected provinces may suffer more damage. Furthermore, industry structure, the energy mix, power plant scale, and infrastructure in a province may affect firms' responses to long-term droughts. We present the results of estimating equation (2) in Tables A3 and A4 in the Appendix. Figure 2 shows the heterogeneity effects of the southwestern drought on output, revenue, employment, and assets. We find that the energy-intensive sectors in Sichuan and Guizhou were more affected by drought because relatively more energy-intensive firms are located here. The hydropower firms in all provinces were significantly affected. The southwestern drought shifted the energy mix in this region from hydropower towards thermal power generation, especially in Guizhou and Yunnan. The hydropower's share in Guizhou's energy mix was much smaller than in Yunnan and, thus, the southwestern drought induced a large increase in its thermal power production, namely 187.2% for output and 82.1% for employment (Table A3, columns (9) and (11)). Although Chongqing sustained less damage from the drought, there was a significant increase of 51.3% (Table A3 column (11)) in the employment of its thermal power firms there because of its lower hydropower share and large electricity demand. This shift was not observed in the other two provinces, but the outputs and revenues of their hydropower firms were negatively and significantly affected. Sichuan Province is very close to the three largest hydroelectricity power stations in China—the Three Gorges Dam, Xiluodu Dam, and Xiangjiaba Dam—which makes it more adaptable to extreme droughts. The southwestern drought also decreased the assets of firms in all industries. The consumption of inventory for production and decrease in long-term investment during the drought can explain this.

[Figure 2]

[Figure 3]

The estimated results over time are summarized in Table A4 in the Appendix. The drought is associated with a reduction in the output, revenue, employment, and assets of energy-intensive and hydropower firms since 2009. Figure 3 reveals the estimated effects on power production over time. Specifically, Figures 3-(a) and 3-(b) show the effects on the output and revenue of the power sector. We find a similar trend in these two figures. The negative effects on output and revenue of hydropower firms lasted 5 years from 2009 to 2013, and the largest decrease of 21.6% (Table A4 column (5)) in output was recorded in 2012 while a decrease of 28.1% (Table A4, column (6)) in revenue was observed in 2011. However, the positive effects on the output and revenue of thermal power firms lasted 3 years, with the strongest effects being registered in 2009, immediately after the drought, after which the effects became weaker. Figure 3-(c) shows that the southwestern drought decreased employment for hydropower firms, but their employment was quickly restored immediately after 2011. The effects on the employment of thermal power firms lasted longer and peaked in 2011. Finally, the negative effects on assets lasted for a longer time and showed no sign of dissipating. Long-term investment in the power sector in the southwestern region could have been influenced by drought. We also explore the effects of drought on the production of other power firms, but the results are not shown in the figures because the sample share is too small to reveal long-term effects. The other power firms, including nuclear power, solar power, wind power, and other renewable energy firms, responded positively and quickly to the drought, which means they could be good alternative sources of power generation in the short term.

6 Environmental Impact

6.1 Carbon Emissions by the Southwestern Drought

The southwestern drought affected not only the economic activities of the power and energy-intensive sectors, but also the GHG emissions in the drought-affected regions. We hypothesize that the drought led to more GHG emissions in the southwest due to the higher thermal power generation. However, the overall effect on emissions is not clear. Although the number of thermal power firms is much smaller than that of energy-intensive firms, we have two reasons to believe that the thermal power sector plays a more decisive role in net emissions. First, the average output (2006–2013 with full sample) of thermal power firms in the southwest is much higher than that of energy-intensive firms—938 million yuan versus

276 million yuan (outputs are deflated to 2015 values using the GDP deflator). Second, the emission intensity of the power sector is much higher than that of the other sectors.

Previous studies have estimated China's regional and sectoral CO_2 emissions using various approaches. Due to the uncertainty of China's energy statistics, most researchers (Peters et al., 2006; Liu et al., 2012; Liu et al., 2015; Shan et al., 2016) propose new energy consumption data for CO_2 estimations. For instance, Liu et al. (2015) adopt the apparent consumption method and update emission factors to recalculate China's CO_2 emissions. They find that the emission factors for Chinese coal are, on average, 40% lower than the IPCC default values and China's cumulative CO_2 emissions from fossil fuel combustion and cement production have been overestimated for 2000–2013. Shan et al. (2016) follow the previous study and recalculate the Chinese provincial CO_2 emissions and discuss emissions from different sectors. They divide the fossil fuel CO_2 emissions for 16 sectors based on the energy balance table. They find that most CO_2 emissions are produced by thermal power, industrial final consumption, petroleum refineries, and coal washing.

Building on previous studies, we extract energy consumption data from the energy balance tables in the China Energy Statistical Yearbook (CESY) for the five southwestern provinces from 2006 to 2008. Our calculation of sectoral emission intensity is based on the mass balance of energy and the accounting process proposed by Liu et al. (2015) and Shan et al. (2016). The estimation of CO_2 emissions is conducted in two steps. The first step is to calculate the sectoral emission intensities[6] in the five southwestern provinces from 2006 to 2008. Unlike the energy balance table, the sectoral output in the statistical year books contains 39 industrial sectors. Therefore, the energy used for the power sector (two-digit industry code=44) is measured by the energy use of thermal power and heating supply sectors based on the "input & output of transformation" sectors in the energy balance table. The energy used for processing petroleum and coking (industry code=25) is measured by the energy use of petroleum refineries and coking sector based on the "input & output of transformation" sectors in the energy balance table. Furthermore, the energy used for the other four energy-intensive sectors (two-digit industry code=26, 30, 31, 32) is measured by the energy use of the industry sector (non-energy use is excluded) based on the "final consumption" sectors in the energy balance table. The second step is to combine the sectoral emission intensities with our DDD estimation results to estimate the change in sectoral CO_2 emissions caused by the drought.

$$Emission_j = \frac{44}{12} \times \sum_{n=1}^{3} AD_{ij} \times EF_i \tag{3}$$

Equation (3) is the general form used to calculate the sectoral CO_2 emissions in the first step. AD_{ij} is the activity data, that is, the energy consumption of primary fuel type i in physical units (metric tons) in sector j, i=raw coal, crude oil, and natural gas; j=thermal power and heating supply, petroleum refineries and coking, and industry sectors. EF_i is the updated carbon emission factor for primary fuel type i, which is assumed to be the same across provinces and time.

[Table 5]

Table 5 reports the sectoral emission intensity of each southwestern province during 2006–2008. The emission intensities show a tendency of decreasing and the thermal power and heating supply sectors have much higher average emission intensities than the other sectors. Moreover, poorer provinces (measured by total output) have higher emission intensities, which is consistent with the results of previous studies. Energy intensities also vary across provinces. Liu et al. (2012) use final the input/output consumption method to obtain the sectoral/regional CO_2 emission intensity during 1997–2009. Compared to their results, some of our emission intensity values in 2006 and 2007 seem unreasonable. Therefore, the sectoral emission intensities in 2008 are used to calculate the CO_2 emissions caused by the drought. Additionally, we use the average value of emission intensities for petroleum refineries and coking and industry sectors as a proxy for energy-intensive sectors' emission intensity.

Using the estimated coefficients in column (4) of Table 2, we calculate that the southwestern drought caused a decrease of 7.8% in the output of the energy-intensive firms, or 17,339.4 million yuan,[7] and an increase of 34.6% in the output of thermal power firms, or 6,959.5 million yuan.[8] Since the emission intensities of these two sectors are 3.77 and 10.03, respectively, the CO_2 emissions from the energy-intensive sectors decreased by 6,536,954 tons, whereas the CO_2 emissions from the power sector increased by 6,980,379 tons. Therefore, the net CO_2 emissions from fossil fuels in 2009–2013 in the southwest increased by about 443,425 tons as a result of the extreme drought.

6.2 Discussion

This study does not consider the improvements in technology and energy efficiency after 2008, which may lead to an overestimation of the carbon emissions due to the southwestern drought. The net carbon emissions depend on the amount of the increase in the thermal power sector and decrease in the energy-intensive sectors during the drought, for which provincial sectoral energy intensity is the determinant factor. Over the past two decades, high-energy-consuming and low-end manufacturing industries have gradually transferred from the eastern region to the central and western regions due to a series of policies issued by the Chinese government to promote industrial transfers and regional structure adjustments (Zhao and Lu, 2019). Because the western region is rich in energy resources and the energy price is lower than in other regions, enterprises usually choose to input more energy in the production process (Tan and Lin, 2018). This results in the higher energy intensity of the firms in the western region compared to other regions (Dong et al., 2018; Tan and Lin, 2018; Zhao and Lu, 2019), which consequently increases the energy vulnerability of the former region. Policies promoting energy conversion and improving the technical efficiency of the power and energy-intensive sectors are thus crucial in mitigating the negative environmental impacts of extreme drought.

7 Conclusions

This study has examined the impact of the southwestern drought on the industrial outcomes of the power and energy-intensive sectors. By using an 8-year firm-level balanced panel data, we explored the responses of power and energy-intensive firms to the long-term water and power shortages caused by the extreme drought. We found that the impacts of the southwestern drought are heterogeneous across sectors. In the southwestern region, firms in the energy-intensive industries sustained more damage during the drought than those in the power sector. Meanwhile, the accumulative effects on the power sector depend on the regional energy mix. Since the long-term water shortage affected hydropower generation, the southwestern drought generated more thermal power. Our findings suggest that energy-driven industries are vulnerable to extreme climate changes, especially in regions with a high dependence on water resources. It might thus be necessary to include drought adaptive measures in the development policies for water-abundant areas.

We also find that ownership type affected firms' responses to the disaster event. In particular, collectively-owned and private firms in the power and energy-intensive sectors were affected least by the southwestern drought. They adopted two behavioral patterns in response to policies such as powering rationing during the drought. If they responded positively, they may have developed adaptive behaviors towards disasters such as droughts. However, if they responded negatively, they may have simply ignored the policy and caused more damage to the total welfare. Moreover, foreign firms sustained the largest damage during the drought, which could influence foreign investment. Conversely, SOEs may have played a more social or political role during the drought. The distribution of firms' ownership types in one region could also be an important consideration for disaster management policies.

We further estimated the environmental impact of the southwestern drought. Our results imply that the drought not only had a detrimental impact on economic activities, but also led to CO_2 emissions of around 443,425 tons more from the thermal power sector. As the world's largest carbon emitter, China plays an important role in global climate change mitigation and has made commitments to achieve specific mitigation targets by 2030 (Shan et al., 2016; Zheng et al., 2019). However, extreme weather and natural disaster risk undermine these efforts against climate change. Our regression analysis provides evidence that natural disasters such as extreme droughts will likely cause economic loss, while increasing carbon emissions. Policies aiming to reduce the energy vulnerability to climate change during clean energy transition must be based on a solid understanding of what constrains regional industrial sectors in terms of clean energy adoption.

Our study has several limitations. First, the external validity of the findings is limited as we focus on extreme droughts in regions with high shares of hydropower. Future studies could thus explore the impacts of different disaster types on power industries and the energy mix. It is possible that extreme droughts have different effects on the power and energy-intensive sectors in arid regions. Second, missing data may have resulted in estimation bias. The main dependent variables of output and assets have a large amount of missing data, while the employment variable is not consistent before and after 2010. More thorough surveys are therefore needed for detailed analyses. Finally, this study focuses only on production activities, and more research on the association between extreme disasters and firm location choices or firm migration behaviors is needed to shed more light on the response decisions of firms towards disasters.

In conclusion, our results suggest that the effects of extreme drought vary across regions and industries and last a long time. Although the decrease in the economic activities of some industries might lead to less carbon emissions during extreme disasters, the electricity demand would still lead to a net increase in carbon emissions. Since there is no efficient substitution for thermal power in the short term, policies to improve energy efficiency and decrease emission intensity are necessary. The southwestern region is under rapid development and the need for electricity is growing. Its high dependence on hydropower could mean more potential need for thermal power generation. Local governments might be motivated to develop hydropower resources, while extreme weather is a challenging issue for water-intensive power plants. More policies on hydropower generation should be implemented to support their roles in strengthening energy security and mitigating climate change.

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Tables

Table 1 Summary statistics

Variable	Control group (1+2) Mean	Control group (1+2) Std. dev.	Control group (1+2) N	Treatment group Mean	Treatment group Std. dev.	Treatment group N
Industrial Outcome Data						
Output (million yuan)	270.641	2238.749	593,803	255.032	1505.751	45,113
Revenue (million yuan)	284.572	2504.815	724,475	257.355	1604.025	54,534
Log output	11.164	1.357	593,803	11.202	1.390	45,113
Log revenue	4.327	1.281	724,475	4.340	1.300	54,534
Firm Characteristics						
Age (year)	12.277	9.249	724,475	13.953	11.831	54,544
Employment (person)	428.098	1847.116	684,518	431.402	1147.841	51,990
Assets (million yuan)	233.424	3128.143	724,493	257.084	1713.063	54,543
Power and Energy-Intensive Sectors						
Power and energy-intensive firms	0.188	0.391	724,548	0.290	0.454	54,548
Power firms	0.020	0.140	724,548	0.070	0.255	54,548
Hydropower firms	0.002	0.046	724,548	0.028	0.165	54,548
Thermal power firms	0.005	0.073	724,548	0.004	0.067	54,548
Other power firms	0.00044	0.021	724,548	0.00006	0.007	54,548
Energy-intensive firm	0.168	0.374	724,548	0.220	0.414	54,548

Source: NBS Annual Industrial Firm Survey (2006–2013). Note: All monetary variables are deflated to 2015 values using the GDP deflator (2015=1; World Bank, 2019). We combine the two-digit power industry and energy-intensive industries into the power and energy-intensive sectors; the power sector contains five four-digit electric power industries, namely the hydroelectric, thermal electric, nuclear electric, wind, and other electric power industries. Nuclear power firms and wind power firms are combined with other power firms as variable "other power firms" in this study.

Table 2 Baseline results

	Log output				Log revenue			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Drought × Post	-0.146**	-0.052			-0.164***	-0.059*		
× Power and Energy-Intensive	(0.055)	(0.038)			(0.058)	(0.031)		
Drought × Post × Energy-Intensive			-0.072**	-0.078**			-0.070**	-0.076**
			(0.034)	(0.034)			(0.033)	(0.033)
Drought × Post × Power			0.018				-0.020	
			(0.038)				(0.030)	
Drought × Post × Hydro				-0.201***				-0.216***
				(0.019)				(0.017)
Drought × Post × Thermal				0.346***				-0.088***
				(0.047)				(0.032)
Drought × Post × Other				0.523***				0.213***
				(0.022)				(0.020)
Firm FE	no	yes	yes	yes	no	yes	yes	yes
Year FE	yes	yes	yes	yes	yes	yes	yes	yes
Year-province FE	yes	yes	yes	yes	yes	yes	yes	yes
Year-industry FE	yes	yes	yes	yes	yes	yes	yes	yes
Province-industry FE	yes	yes	yes	yes	yes	yes	yes	yes
Observations	638899	638899	638899	638899	778989	778989	778989	778989
Adjust R^2	0.222	0.844	0.844	0.844	0.223	0.885	0.885	0.885

Note: The dependent variables are the logs of output and revenue. Each column presents the results from the DDD model, estimated by high-dimensional fixed-effects regressions. The constant term is included but not reported. Standard errors are between parentheses and clustered at the two-digit industry and year-province levels. * p<0.1, ** p<0.05, and *** p<0.01.

Table 3 Results without control group 2

	Log output			Log revenue		
	(1)	(2)	(3)	(4)	(5)	(6)
Drought × Post	-0.043			-0.058**		
× Power and Energy-Intensive	(0.033)			(0.027)		
Drought × Post × Energy-Intensive		-0.055*	-0.061**		-0.059**	-0.063**
		(0.029)	(0.028)		(0.028)	(0.028)
Drought × Post × Power		0.003			-0.054	
		(0.040)			(0.033)	
Drought × Post × Hydro			-0.219***			-0.248***
			(0.017)			(0.018)
Drought × Post × Thermal			0.328***			-0.122***
			(0.047)			(0.030)
Drought × Post × Other			0.524***			0.199***
			(0.026)			(0.020)
Firm FE	yes	yes	yes	yes	yes	yes
Year FE	yes	yes	yes	yes	yes	yes
Year-province FE	yes	yes	yes	yes	yes	yes
Year-industry FE	yes	yes	yes	yes	yes	yes
Province-industry FE	yes	yes	yes	yes	yes	yes
Observations	383714	383714	383714	468697	468697	468697
Adjust R^2	0.843	0.843	0.843	0.884	0.884	0.884

Note: The dependent variables are the logs of output and revenue. Each column presents the results from the DDD model, estimated by high-dimensional fixed-effects regressions. The constant term is included but not reported. Standard errors are between parentheses and clustered at the two-digit industry and year-province levels. * p<0.1, ** p<0.05, and *** p<0.01.

Table 4 Estimated effects on industrial outcomes by ownership type

	Log output				Log revenue			
	SOE (1)	COE (2)	Private (3)	Foreign (4)	SOE (5)	COE (6)	Private (7)	Foreign (8)
Drought × Post × Energy-Intensive	-0.121*	0.037	-0.057	-0.098**	-0.104	-0.048	-0.050	-0.131**
	(0.067)	(0.083)	(0.036)	(0.040)	(0.072)	(0.088)	(0.034)	(0.064)
Drought × Post × Hydro	-0.220***	-0.243***	-0.020	-0.162***	-0.225***	-0.233***	-0.065***	-0.138***
	(0.032)	(0.051)	(0.014)	(0.030)	(0.028)	(0.035)	(0.022)	(0.046)
Drought × Post × Thermal	0.276***	0.400***	0.000	-0.371***	-0.122***	0.245***	0.264***	-0.365***
	(0.065)	(0.060)	(0.000)	(0.086)	(0.024)	(0.075)	(0.034)	(0.084)
Firm FE	yes	yes	yes	yes	yes	yes	yes	yes
Year FE	yes	yes	yes	yes	yes	yes	yes	yes
Year-province FE	yes	yes	yes	yes	yes	yes	yes	yes
Year-industry FE	yes	yes	yes	yes	yes	yes	yes	yes
Province-industry FE	yes	yes	yes	yes	yes	yes	yes	yes
Observations	44571	29038	423323	119318	52927	33978	513050	151028
Adjust R^2	0.910	0.884	0.832	0.868	0.947	0.912	0.872	0.905

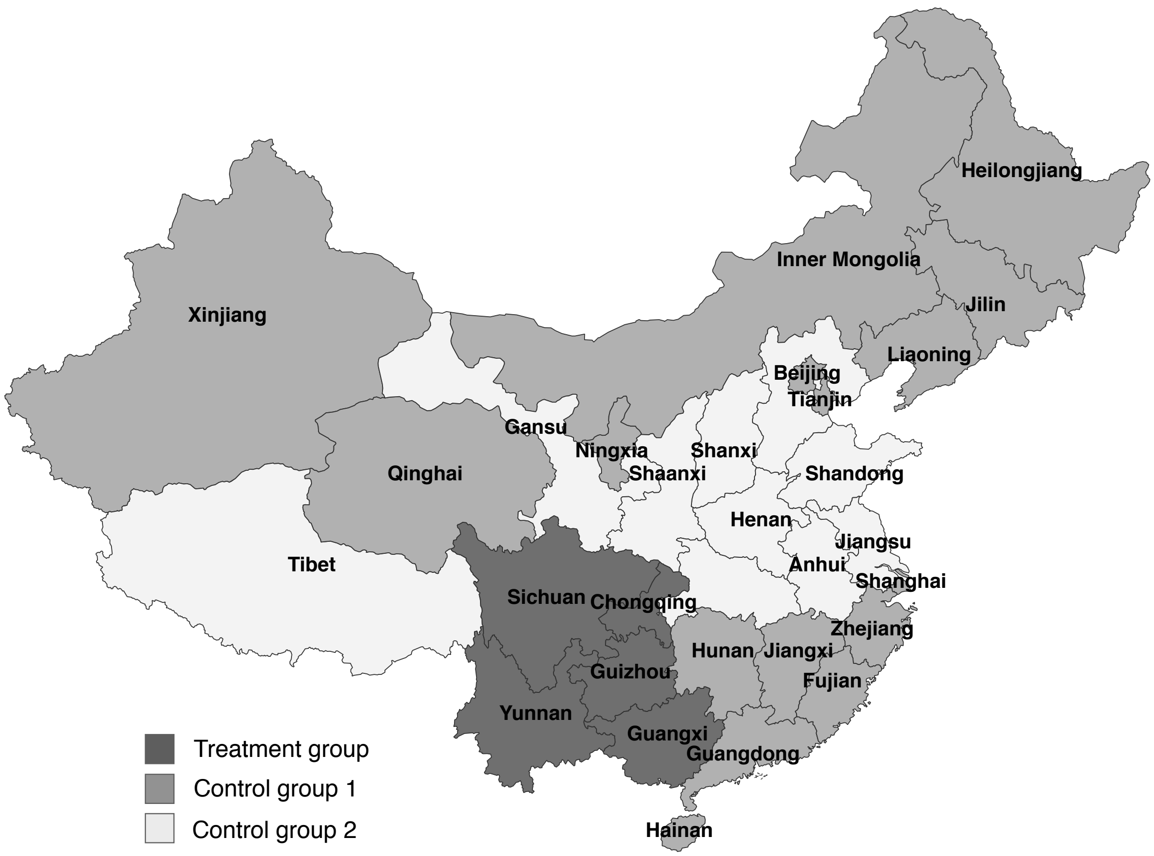
Note: The dependent variables are the logs of output and revenue. Each column presents the results from the DDD model, estimated by high-dimensional fixed-effects regressions. The constant term is included but not reported. Standard errors are between parentheses and clustered at the two-digit industry and year-province levels. * p<0.1, ** p<0.05, and *** p<0.01.

Table 5 Sectoral emission intensity by province during 2006–2008

Unit: tCO_2/10000Yuan	Guangxi	Chongqing	Sichuan	Guizhou	Yunnan
year=2006					
Thermal power and heating supply sector	11.21	14.92	14.30	19.21	18.42
Petroleum refineries and coking sector	9.31	6.58	6.50	42.83	53.60
Industry sector	1.44	1.23	0.44	2.51	1.28
year=2007					
Thermal power and heating supply sector	9.35	14.14	9.29	17.47	17.45
Petroleum refineries and coking sector	7.77	1.95	5.54	43.50	13.80
Industry sector	1.08	0.79	0.52	1.97	0.86
year=2008					
Thermal power and heating supply sector	6.73	10.57	7.59	13.89	11.38
Petroleum refineries and coking sector	6.59	0.79	3.25	10.99	11.73
Industry sector	0.83	1.04	0.60	1.15	0.75

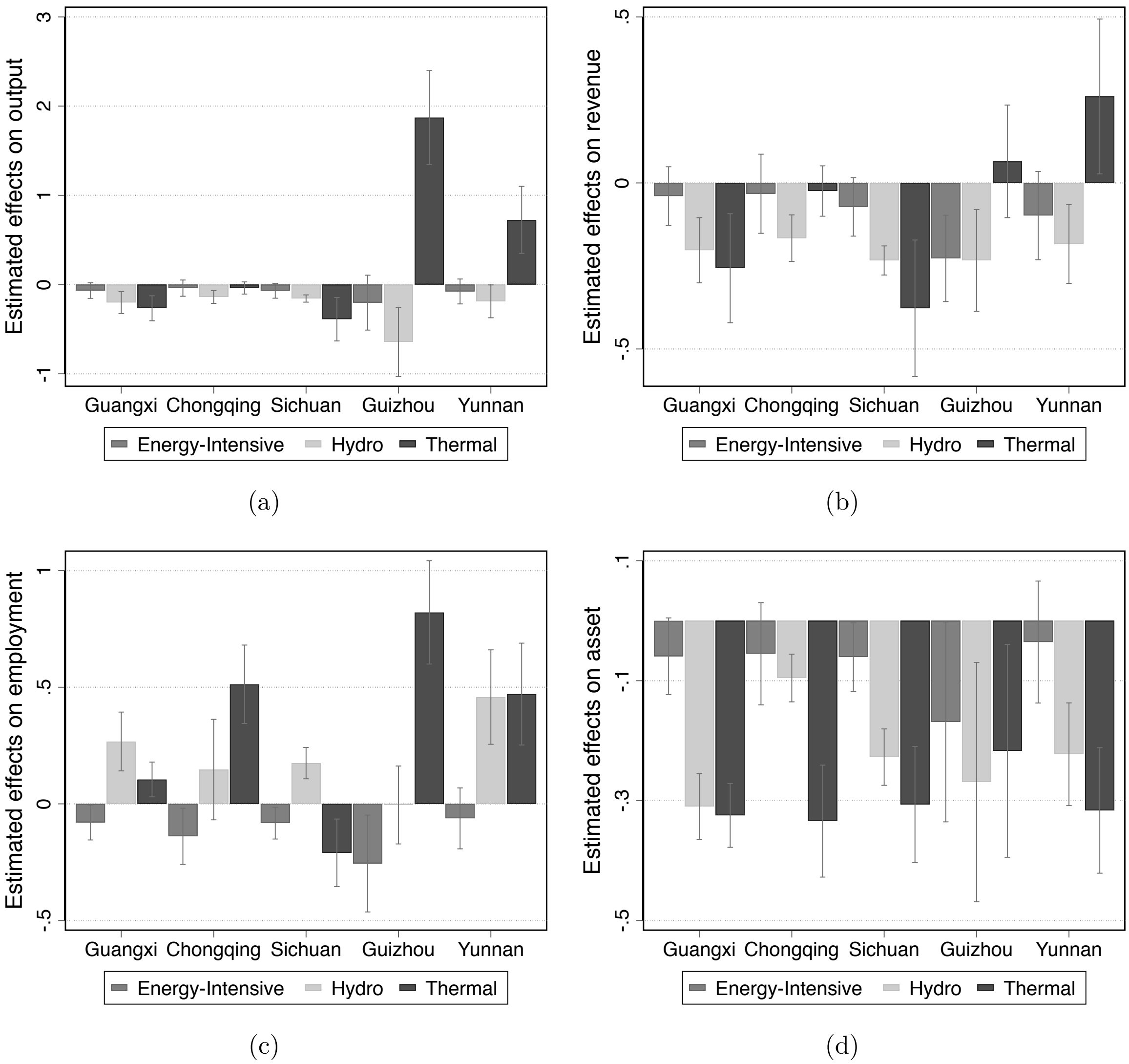
Note: Sectoral emission intensity=sectoral CO_2 emissions/sectoral output. We use the updated carbon emission factors of raw coal, crude oil, and natural gas, which are 0.499, 0.838, and 0.590, respectively. Sectoral outputs are deflated to 2015 values using the GDP deflator (2015=1; World Bank, 2019).

Figures



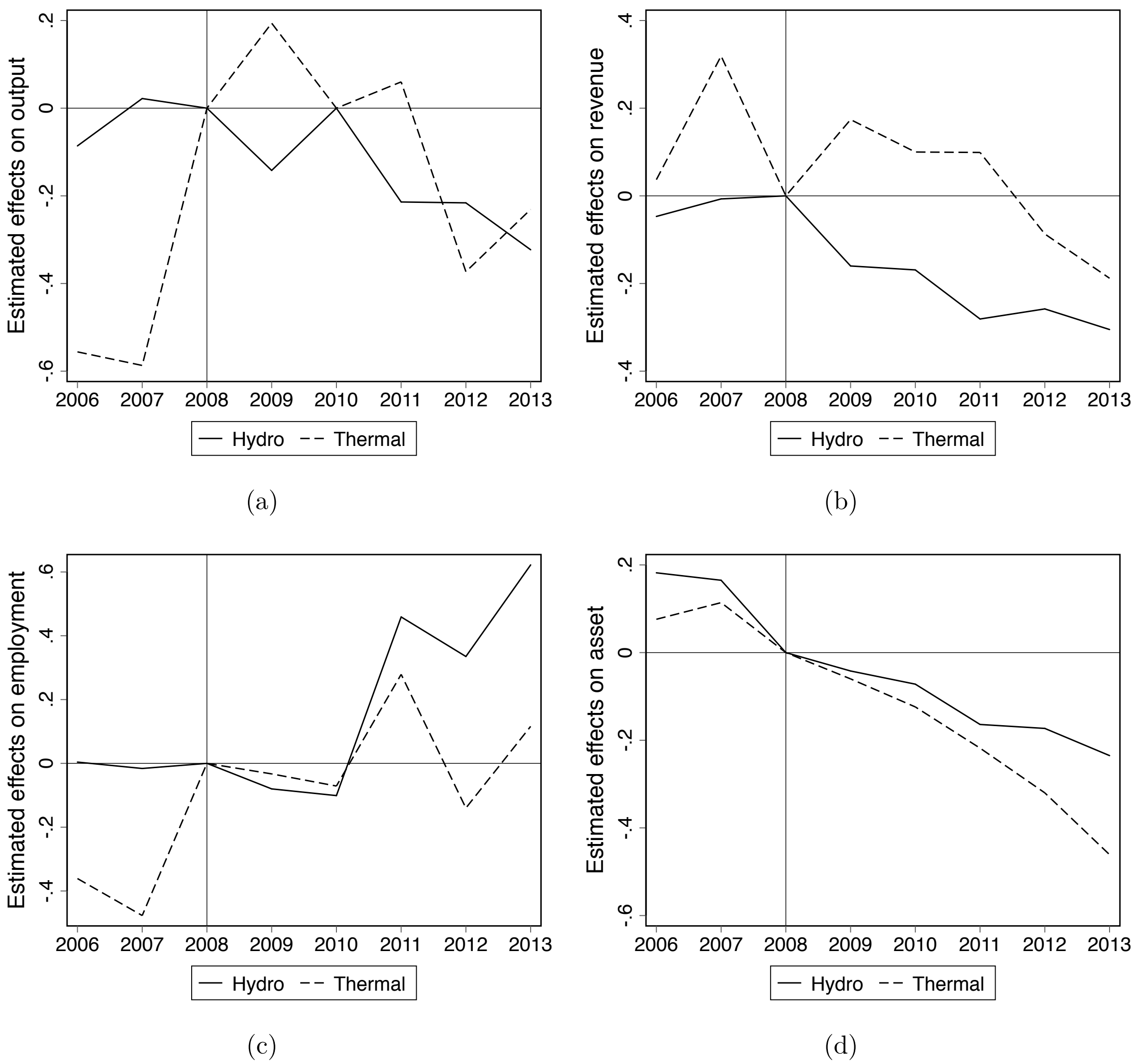
Source: EM-DAT Database, 2006–2013. Note: Provinces in control group 1 and 2 were not affected by the 2009/2010 southwestern drought. However, control group 2 includes provinces affected by another extreme drought that occurred in 2011, after the southwestern drought. The 2011 drought affected most wheat-producing regions over the middle and lower reaches of the Yangtze River. Water shortages were associated with the occurrence of both droughts. We use two control groups for the robustness check.

Fig. 1. Treatment and control groups



Note: The above figures plot the estimated effects of drought on log output, log revenue, log employment, and log assets across drought-affected provinces. The 95% confidence bands were added as gray solid lines. The coefficients are obtained by estimating equation (2).

Fig. 2. Effects on industrial outcome by province



Note: The above figures plot the coefficients from estimating equation (2), that is, DDD models with multiple time periods. Year 2008 is the baseline. Figure (a) shows the annual effects of the southwest drought on the log output of electric power firms, and the 2010 effect is automatically generated by averaging the effects of 2009 and 2011.

Fig. 3. Effects on power sectors over time

Notes

[1]The southwestern region includes five provinces and one municipality: Guangxi, Sichuan, Guizhou, Yunnan, Xizang, and Chongqing.

[2]The three most developed economic zones are the Yangtze River Delta Economic Zone, Jingjinji Metropolitan Region, and Pearl River Delta Economic Zone.

[3]The average output and revenue of the energy-intensive sectors in the treatment group before 2009 were 150.6 million yuan and 167.3 million yuan, respectively.

[4]The average output and revenue of the hydropower sector in the treatment group before 2009 were 83.8 million yuan and 84.0 million yuan, respectively.

[5]The average output and revenue of the thermal power sectors in the treatment group before 2009 were 648.7 million yuan and 652.4 million yuan, respectively.

[6]Sectoral emission intensity=Sectoral carbon emissions/Sectoral output. The sectoral output data are collected from the Statistical Year Book of each southwestern province, and we use the sectoral gross industrial output for all SOEs and non-SOEs above a designated size.

[7]The number of energy-intensive firms is 1,482 and the output loss of each firm is 11.7 million yuan, as calculated in Subsection 5.2.

[8]The number of thermal power firms is 31 and the increase in the output of each firm is 224.5 million yuan, as calculated in Subsection 5.2.

Appendix

Table A1 Power and Energy-Intensive industries classification code

Two-digit industries
25 — Processing of petroleum, coking, processing of nucleus fuel
26 — Manufacture of raw chemical material and chemical products
30 (31*)— Manufacture of non-metallic mineral products
31 (32*) — Smelting and pressing of ferrous metals
32 (33*) — Smelting and pressing of non-ferrous metals
44 — Production and distribution of electric power and heat power
Four-digit electric power industries
4411 — Thermal power generation
4412 — Hydropower generation
4413 — Nuclear power generation
4414 — Wind power generation
4419 — Other power generation

Source: Statistical Bulletin on National Economic and Social Development in 2010.
31*, 32* and 33* indicate the old CSIC code used in the dataset before 2013.

Table A2 Balancing test results

Variable	Unmatched/Matched	Treated mean	Control mean	%Bias	%Reduct bias	T-test (P-value)
Age	U	12.511	10.796	16.4		0.000
	M	12.511	12.292	2.1	87.2	0.270
Industry	U	26.864	27.891	-9.8		0.000
	M	26.864	26.797	0.6	93.5	0.731
Ownership	U	3.0534	3.3789	-20.9		0.000
	M	3.0534	3.0428	0.7	96.8	0.711

Table A3 Estimated effects across drought-hit provinces

	e=Energy-Intensive				e=Hydropower				e=Thermal power			
	Output	Revenue	Employment	Asset	Output	Revenue	Employment	Asset	Output	Revenue	Employment	Asset
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Guangxi × Post ×$Energy^e$	-0.067	-0.040	-0.080**	-0.059*	-0.202***	-0.203***	0.267***	-0.310***	-0.265***	-0.257***	0.105***	-0.325***
	(0.043)	(0.044)	(0.037)	(0.032)	(0.061)	(0.049)	(0.062)	(0.027)	(0.069)	(0.081)	(0.037)	(0.026)
Chongqing × Post ×$Energy^e$	-0.040	-0.033	-0.139**	-0.055	-0.139***	-0.166***	0.147	-0.095***	-0.038	-0.024	0.513***	-0.334***
	(0.045)	(0.059)	(0.059)	(0.042)	(0.036)	(0.035)	(0.107)	(0.020)	(0.034)	(0.038)	(0.083)	(0.046)
Sichuan × Post ×$Energy^e$	-0.071*	-0.072	-0.083**	-0.061**	-0.156***	-0.233***	0.175***	-0.227***	-0.388***	-0.378***	-0.210***	-0.306***
	(0.041)	(0.044)	(0.034)	(0.028)	(0.020)	(0.022)	(0.033)	(0.023)	(0.120)	(0.102)	(0.072)	(0.048)
Guizhou × Post ×$Energy^e$	-0.203	-0.227***	-0.256**	-0.169**	-0.644***	-0.233***	-0.005	-0.269***	1.872***	0.065	0.821***	-0.217**
	(0.152)	(0.064)	(0.103)	(0.082)	(0.192)	(0.076)	(0.083)	(0.099)	(0.262)	(0.084)	(0.110)	(0.088)
Yunnan × Post ×$Energy^e$	-0.077	-0.098	-0.062	-0.036	-0.188**	-0.184***	0.458***	-0.223***	0.725***	0.261**	0.471***	-0.316***
	(0.069)	(0.066)	(0.065)	(0.050)	(0.091)	(0.059)	(0.100)	(0.042)	(0.186)	(0.115)	(0.108)	(0.052)
Firm FE	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes
Year FE	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes
Year-province FE	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes
Year-industry FE	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes
Province-industry FE	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes
Observations	638769	778837	736339	778864	638769	778837	736339	778864	638769	778837	736339	778864
Adjust R^2	0.844	0.885	0.815	0.927	0.844	0.885	0.815	0.927	0.844	0.885	0.815	0.927

Note: 2008 is the baseline year. We restrict the sample to observations on common support in this analysis. The dependent variables are the logs of output, revenue, employment, and assets. This table shows the effects of drought on industrial outcomes of the power industries across provinces by the southwestern drought. The constant term is included but not reported. Standard errors are between parentheses and clustered at the two-digit industry and year-province levels. * is p<0.1, ** is p<0.05, and *** is p<0.01.

Table A4 Estimated effects over time

	e=Energy-Intensive				e=Hydropower				e=Thermal power			
	Output	Revenue	Employment	Asset	Output	Revenue	Employment	Asset	Output	Revenue	Employment	Asset
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Drought $\times Energy^e \times$ 2006	0.076*	0.079**	0.071***	0.057***	-0.086**	-0.047*	0.004	0.182***	-0.556***	0.037	-0.361***	0.076***
	(0.042)	(0.033)	(0.019)	(0.016)	(0.041)	(0.027)	(0.030)	(0.013)	(0.106)	(0.070)	(0.067)	(0.025)
Drought $\times Energy^e \times$ 2007	0.023	0.046***	0.048***	0.030**	0.022	-0.007	-0.016	0.165***	-0.587***	0.319***	-0.477***	0.114***
	(0.024)	(0.008)	(0.014)	(0.013)	(0.021)	(0.017)	(0.032)	(0.011)	(0.154)	(0.033)	(0.089)	(0.027)
Drought $\times Energy^e \times$ 2009	-0.031	-0.033	-0.018**	-0.015	-0.142***	-0.160***	-0.080***	-0.042**	0.194**	0.174***	-0.033	-0.060**
	(0.022)	(0.023)	(0.008)	(0.018)	(0.029)	(0.021)	(0.020)	(0.019)	(0.089)	(0.035)	(0.040)	(0.024)
Drought $\times Energy^e \times$ 2010	0.000	-0.020	-0.027	-0.017	0.000	-0.169***	-0.101***	-0.072***	0.000	0.100**	-0.071***	-0.124***
	(0.000)	(0.033)	(0.017)	(0.018)	(0.000)	(0.023)	(0.028)	(0.015)	(0.000)	(0.041)	(0.023)	(0.025)
Drought $\times Energy^e \times$ 2011	-0.034	-0.029	-0.104***	-0.044**	-0.214***	-0.281***	0.459***	-0.164***	0.060	0.099**	0.279***	-0.218***
	(0.026)	(0.030)	(0.030)	(0.017)	(0.027)	(0.021)	(0.034)	(0.016)	(0.095)	(0.039)	(0.063)	(0.027)
Drought $\times Energy^e \times$ 2012	-0.060	-0.048	-0.132***	-0.062**	-0.216***	-0.258***	0.335***	-0.173***	-0.373***	-0.087**	-0.140**	-0.320***
	(0.038)	(0.030)	(0.031)	(0.023)	(0.035)	(0.024)	(0.046)	(0.017)	(0.086)	(0.036)	(0.060)	(0.025)
Drought $\times Energy^e \times$ 2013	-0.079*	-0.054	-0.080	-0.066	-0.323***	-0.305***	0.622***	-0.235***	-0.231**	-0.188***	0.116*	-0.461***
	(0.046)	(0.047)	(0.051)	(0.043)	(0.045)	(0.025)	(0.030)	(0.023)	(0.091)	(0.054)	(0.065)	(0.040)
Firm FE	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes
Year FE	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes
Year-province FE	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes
Year-industry FE	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes
Province-industry FE	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes
Observations	638769	778837	736339	778864	638769	778837	736339	778864	638769	778837	736339	778864
Adjust R^2	0.844	0.885	0.815	0.927	0.844	0.885	0.815	0.927	0.844	0.885	0.815	0.927

Note: 2008 is the baseline year. We restrict the sample to observations on common support in this analysis. The dependent variables are logs of output, revenue, employment, and assets. This table shows the effects of drought on industrial outcomes of the power industries over time. The constant term is included but not reported. Standard errors are between parentheses and clustered at the two-digit industry and year-province levels. * is p<0.1, ** is p<0.05, and *** is p<0.01.