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Abstract

This paper uses year-to-year fluctuations in temperature within counties to identify its effects on economic outcomes of Chinese manufacturing firms. We find four primary results. First, profit exhibits nonlinear responses to temperature. Profit decreases with higher summer temperatures and increases with higher winter temperatures. With temperature bins as temperature variables, profit increases with temperature up to 12-15°C, and then declines at higher temperatures. Second, higher temperatures have wide-ranging effects – raising labor costs, hurting innovation activity, and reducing industrial output by decreasing TFP, investment and capital stock. Third, these temperature effects differ across regions, ownership types and industries. Lastly, if no additional adaptation is undertaken, the total profit of Chinese manufacturing firms is projected to decline annually by 2.5-9.2% during the mid-21st century, equivalent to a loss of CNY 29.5-108.6 billion in 2007 values.

Key Words: temperature, profit, industrial output, TFP, labor costs, innovation activity

JEL Codes: Q51, Q54, D24, O14, O44

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Xiaoguang Chen and Lu Yang*

1. Introduction

With global average temperatures predicted to continue to rise, a rapidly growing body of research has examined whether and to what extent rising temperatures affect the industrial sector. Most existing studies evaluating the impacts of rising temperature on the industrial sector have focused on estimating the relationship between temperature and industrial output. These studies find adverse impacts of high temperatures on industrial output (see Chen and Yang, 2017; Dell et al., 2014; Hsiang, 2010; Zhang et al., 2018). However, little is known about the effect of temperature on profit, which is a key indicator of whether a firm has long-term growth potential. In this paper, we ask whether temperature has affected industrial firms' profit, and, if so, to what extent and through which channels. Because the industrial sector plays a dominant role in the Chinese economy, understanding these impacts is essential to develop efficient strategies to cope with future warming.

Conceptually, whether temperature has any meaningful impacts on profit is unclear. On the one hand, by negatively affecting labor productivity and total factor productivity (TFP), high temperatures reduce industrial output (Zhang et al., 2018). On the other hand, temperature may influence market prices of output and inputs used for production (i.e., labor and capital). If demand functions are invariant to temperature changes, a reduced supply of final goods stemming from high temperatures may result in lower input prices due to reduced demand for inputs and higher market prices of the final goods. Therefore, the net effect of temperature on profit is unclear.

To shed light on the relationship between temperature and profit, we analyze a rich firm-level data set of Chinese manufacturing firms from 1998 to 2007, combined with a fine-scale daily weather data set over the same period. China provides a compelling setting to study the effect of temperature on profit, for several reasons. First, China has witnessed significant warming. The increase in annual average surface temperature was 0.5-0.8°C per year over the past century, which is higher than the average global temperature rise over the same period (Ding

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et al., 2007). Second, China's industrial sector has been experiencing rapid growth of over 8% annually during the last four decades. Currently, the industrial sector accounts for approximately 43% of China's GDP. Third, our firm-level data set comprises all industrial firms in China with annual sales above CNY 5 million. The number of firms covered by the data set varies from approximately 157,000 in 1998 to approximately 325,000 in 2007. These firms are widely distributed across China's industrial heartland and they have different types of ownership, enabling us to explore the heterogeneity in the effect of temperature on profit across regions, ownership types, and industries. We are unaware of a comparable data set used for assessing the effect of temperature on the industrial sector in any other developing country.

We identify the temperature effect on profit by exploiting year-to-year fluctuations in temperature within firms. We isolate the temperature effect from other confounding factors by including a comprehensive set of weather variables that exhibit simultaneous variations with temperature. As additional weather variables, we incorporate rainfall, sunshine hours, air pressure, relative humidity, and wind speed. Time-invariant firm fixed effects, industry × year fixed effects, and region × year fixed effects are incorporated to minimize the estimation biases stemming from omitted variables.

Our analysis reveals three primary findings. First, we discover a nonlinear relationship between profit and temperature. Profit declines with higher summer temperatures and increases with higher winter temperatures. Holding all else equal, a 1°C increase in average summer temperatures causes a 3.8-6.2% reduction in profit across a variety of alternative model specifications, estimation approaches, and samples. We find that a 1°C increase in average winter temperatures is associated with an increase of 3.4-4.6% in profit, but the estimates are less robust. The finding of the nonlinear responses of profit to temperature holds when we use temperature bins to represent the relationship between temperature and profit. Profit increases with temperature up to 12-15°C, and then declines sharply with higher temperatures. These findings are consistent with prior studies that also find nonlinear impacts of temperature on industrial output (Chen and Yang, 2017; Zhang et al., 2018) and on global economic productivity (Burke et al., 2015).

Second, we find evidence that temperature affects profit through a variety of dimensions. We find that industrial output declines with higher temperatures, mainly through the negative effects of higher temperatures on TFP and investment (and thus capital stock), which are all essential elements for industrial production. In line with Zhang et al. (2018), we find that temperature has a fairly limited impact on labor use. Moreover, higher temperatures lead to an increase in labor costs, as government regulation requires that employers provide high-temperature subsidies to workers during days with the daily maximum temperature (T_{max})

exceeding 35°C.[1] Furthermore, higher temperatures reduce firms' innovation activity, as evidenced by the reduced share of new product sales in relation to the total industrial output value, and this reduced innovation effort could have a detrimental effect on profit. These results may help the development of efficient strategies to mitigate the negative effect of higher temperatures on profit.

Third, we find substantial heterogeneity in the effects of temperature on profit across regions, ownership types, and industries. Higher summer temperatures exert large and significant negative impacts on the profits of industrial firms located in East China, whereas the temperature-profit relationships are insignificant in other regions. Domestic firms that are privately owned are most impacted by higher summer temperatures, while the temperature effects on foreign firms and state-owned enterprises (SOEs) are insignificant because they are likely to take good protective measures on hot days. Among the 39 two-digit industries covered by the data set, special equipment manufacturing, stationary, and furniture are the three industries affected most by higher summer temperatures. Because the production of the three industries occurs mostly indoors, this finding suggests limited adaptation undertaken by the three industries to cope with high temperatures. Higher summer temperatures also lead to substantial profit losses in outdoor industries such as fabricated metal products and rubber. As a result, industrial profit in China is projected to decline annually by 2.5-9.2% on average during the mid-21st century under warming scenarios provided by the global climate model UKMO-HadCM3. This is equivalent to a loss of CNY 29.5-108.6 billion in 2007 values.

Several studies have used macro-level data to analyze the effects of temperature on industrial output and found that output declines with high temperatures (Burke et al., 2015; Dell et al., 2012; Hsiang, 2010). The only other detailed economic analyses of the temperature effects on output based on fine-scale firm-level data sets are Cachon et al. (2012), Chen and Yang (2017), and Zhang et al. (2018). Using a weekly production data set from 64 automobile plants in the US over the 1994-2005 period, Cachon et al. (2012) find that a week with six or more days above 32°C can reduce that week's production by approximately 8%. Chen and Yang (2017) and Zhang et al. (2018) analyze firm-level data of Chinese manufacturing firms. Both studies find that output declines with high temperatures and that the response is nonlinear.

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[1] In 2012, the Chinese central government established a regulation – the Administrative Measures on Heatstroke Prevention (available at www.chinasafety.gov.cn/newpage/Contents/Channel_5912/2012/0704/172994/content_172994.htm) – to reduce the adverse impacts of hot weather on public health, work safety and labor productivity. This governmental regulation requires that employers provide high-temperature subsidies to workers during days with the daily Tmax exceeding 35°C. Compared to privately- and collectively-owned domestic firms, foreign firms and state-owned enterprises are more likely to follow this legal requirement.

Aside from providing the first firm-level evidence of the temperature effect on industrial firms' profit, we present a comprehensive interpretation of how temperature affects output and profit. Zhang et al. (2018) show that temperature has negative impacts on output, mainly through the effect of temperature on TFP, with limited effects on labor and capital stock. The present paper finds that high temperature negatively affects both output and profits by reducing investment and capital stock as well as TFP. Moreover, as noted above, we show that higher temperatures can negatively affect profit by raising labor costs and reducing firms' innovation activity.

The remainder of the paper is organized as follows. Section 2 presents a conceptual framework. Section 3 reports data sources. Section 4 describes our empirical strategy. Section 5 presents the main results on the effects of temperature on profit and considers a number of robustness checks. Section 6 explores a variety of channels through which temperature affects profit. Section 7 examines heterogeneity in the effects of temperature on profit. Section 8 projects the impacts of future warming. Section 9 concludes.

2. Conceptual framework

This section sketches a conceptual framework to illustrate channels through which temperature may affect profit. We assume that all firms are profit-maximizing and operate in perfectly competitive markets. Consider a representative firm that uses a Cobb-Douglas production technology and two inputs, labor (L) and capital (K), to produce a single final good (Y):

$$Y = AL^{\alpha}K^{\beta} \tag{1}$$

Here, A refers to this firm's TFP, which is a weighted average of labor and capital productivities. α and β denote output elasticities of labor and capital, respectively. Let P, ω_L and ω_K denote the market prices of the final good, labor, and capital, respectively. The firm's profit can be written as in Equation (2):

$$\pi = P * Y - \omega_L L - \omega_K K \tag{2}$$

Equation (3) below shows that the firm's year-end capital stock is the sum of the year-end capital stock in the previous year (denoted by K_{-1}) and the investment made in the current year (denoted by I), net of capital depreciation (denoted by D).

$$K = K_{-1} + I - D \tag{3}$$

From Equations (1), (2) and (3), we note several things about how temperature may affect profit.

(a)Temperature may affect profit through temperature's effect on output.

As can be seen from Equation 1, temperature affects output for several possible reasons. First, high temperatures are found to have a direct impact on labor productivity by causing discomfort, fatigue, pain, and even cognitive dysfunction, depending on the length of time that workers are exposed to high temperatures (González-Alonso et al., 1999; Zivin and Neidell, 2014). Temperature also impacts machine performance and thus capital productivity (Mostafavi and Agnew, 1996). Because TFP is a weighted average of capital and labor productivities, temperature changes are expected to affect TFP (A in Equation 1). Second, labor and capital inputs may also change with temperature (L and K in Equation 1) (Zivin and Neidell, 2014). Third, prior studies have provided evidence suggesting that temperature significantly affects investors' behavior and stock market returns (Cao and Wei, 2005). By influencing investment decisions (I), temperature may affect capital stock (K in Equation 3).[2]

(b)Temperature may affect profit by altering market prices of output and input.

Several studies have demonstrated that, by affecting labor costs, storage levels (Roberts and Schlenker, 2013), and consumer demand (Henley and Peirson, 1998), temperature can affect the market prices of inputs and output (P, ω_L and ω_K in Equation 2). For instance, high temperatures are expected to increase labor costs in China due to the provision of high-temperature subsidies to workers on extremely hot days (Zhao et al., 2016).

(c)Temperature may affect profit by affecting inventory and innovation activity.

Temperature may affect profit through two additional channels. First, by negatively influencing the performance of drivers and vehicles (Daanen et al., 2003), high temperatures may increase firm inventory levels. Second, when firms are exposed to high temperatures for a long period of time, they may take costly defensive actions to adapt to high temperatures. For example, some firms may install and run air conditioners to mitigate thermal stress on workers. The nature and extent of such adaptations depend on temperature levels. If these adaptations are too costly, they may affect the amount of resources available for R&D and innovation activity. Thus, by increasing inventory levels and reducing R&D spending, high temperatures may generate negative effects on profit.

Based on the above discussion, we divide the various channels through which temperature affects profit into three main categories. The first category focuses on channels by

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[2] In the empirical analyses, we do not examine the temperature effect on capital depreciation, because this variable is typically computed based on an assumed depreciation rate and the year in which the capital was purchased (Nadiri and Prucha, 1996). Thus, it is unlikely to be affected by temperature.

which temperature affects output, including the effects of temperature on TFP, labor, capital stock, and investment. The second category concentrates on the effects of temperature on prices, with a particular focus on labor costs. We do not examine the effect of temperature on output prices, because, unlike wages, output prices did not vary substantially across regions in a given year, due to improved transportation infrastructure and market integration in China in the past two decades (Zheng and Kahn, 2013).[3] The third category focuses on examining whether temperature has any effects on firm inventory levels and innovation activity. We refer to these variables as channel variables.

3. Data and variables

3.1. Firm Data

Our firm-level data are obtained from the annual surveys of Chinese manufacturing and mining firms conducted by the National Bureau of Statistics of China (NBS) for the period of 1998 to 2007. This data set covers state-owned enterprises and non-state-owned enterprises. The latter includes privately owned firms, collectively owned firms, foreign firms, Hong Kong, Macao and Taiwan firms, and mixed-ownership firms, with annual sales above CNY 5 million. The number of firms covered by these surveys varies over time and increases from 157,526 in 1998 to 325,337 in 2007. These firms are located in 31 provinces and province-equivalent municipal cities, and the total output produced by these firms accounts for over 85% of China's total industrial output. These surveys contain 39 two-digit industries, which are specified based on Chinese Industry Classification Codes, and each firm included in the data set is classified into a two-digit industry.

The data set also contains firm identification number (ID) and operation and accounting information. When the firms were first surveyed, they received a unique ID from the NBS. However, many firms received a new ID due to restructuring, merger, acquisition, or changes in ownership. To construct a firm-level longitudinal data set, we follow the procedure described in Brandt et al. (2012) to link firms across the sample period.

Following common practices used by prior studies (for example, see Bai et al., 2009; Cai and Liu, 2009), we exclude observations from the original data set if some key variables have missing or unreasonable values. Specifically, we delete firm-year observations if (*i*) profit to

[3] As discussed below, in addition to weather variables, our empirical model also incorporates industry × year fixed effects and region × year fixed effects, which may absorb most of the variations in output prices. As a result, the effect of temperature on output prices would likely be insignificant, if we were able to collect the output price data.

sales ratio is either below the 0.1% level or above the 99.9% level; (*ii*) value added is either below the 1.0% level or above the 99.0% level; and (*iii*) the number of workers is below 8. We also drop observations if value added, the number of workers, total assets, fixed assets, or total annual sales have missing values or when basic accounting principles are violated, in order to ensure that our regression results are not biased due to misclassified outliers.

After using the above-mentioned procedures to exclude mis-specified observations, we find that firms' profits, which are the sum of the profits from the sales of main products and the profits from the sales of other products, in the remaining sample are positive. We measure a firm's industrial output using value added, which is the difference between total output and intermediate input. Following the prior literature (for example, see Zhang et al., 2018), we estimate firm-level TFP using the Olley-Pakes estimator (Olley and Pakes, 1996). Investment, which is used in the Olley-Pakes estimator, is simply obtained from the equation of motion for the capital stock as shown in Equation (3). Firms also report the number of workers employed, wages, inventory levels, new product sales and total industrial output values. We use wages paid to all workers to measure labor costs. As discussed below, we use the ratio of new product sales to a firm's total industrial output value to measure that firm's innovation activity (Jefferson et al., 2003; Lin et al., 2011).

3.2. Weather Data

We collect daily weather data, including temperature, rainfall, sunshine hours, air pressure, relative humidity, and wind speed, from the China Meteorological Data Sharing Service System (CMDSSS) for the period of 1998 to 2007. The CMDSSS reports daily weather outcomes for about 820 weather stations in China and the data set contains coordinates of each weather station. About 19 Chinese counties have more than one weather station, and the vast majority of other Chinese counties have one weather station. For the 19 counties with more than one weather station, we use the average of the weather variables across weather stations to construct county-level weather variables. We construct weather variables for counties without a weather station from their nearest neighboring counties.

We merge the firm-level data with the county-level weather data by county and year. Thus, industrial firms located in the same county have the same values of weather variables. That yields an unbalanced panel with 1,347,937 observations for years 1998-2007. Our key variables exhibit considerable variability during the sample period (Table A1 in Appendix A shows summary statistics of the data).

4. Empirical Strategy

When examining the effects of temperature on profit, we first use seasonal average temperatures as temperature variables and then define temperature variables as a vector of temperature bins. We use the two different approaches to construct temperature variables for two reasons. First, we want to see whether the effects of temperature on profit differ across seasons. Second, we intend to examine whether estimated temperature effects are sensitive to how temperature variables are constructed.

$$\log E_{i,t} = \alpha_0 Temp_{i,t} + \beta_0 W_{i,t} + \gamma Z_{i,t} + c_i + \varepsilon_{i,t} \quad (4)$$

In Equation (4), firms are indexed by *i* and years are indexed by *t*. $E_{i,t}$ denotes profit and the various channel variables mentioned in Section 2, including output, TFP, labor, capital stock, investment, labor costs, inventory, and innovation activity. We take the natural logs for these variables, with an exception for the innovation variable, and thereby estimated coefficients of weather variables are interpreted as the percentage changes in $E_{i,t}$ with a one-unit increase in weather variables. As noted above, we first construct temperature variables using seasonal average temperatures, which are denoted by $Temp_{i,t}$ in Equation (4) and include average spring temperatures ($Temp^{spring}$), average summer temperatures ($Temp^{summer}$), average fall temperatures ($Temp^{fall}$) and average winter temperatures ($Temp^{winter}$). Other weather variables, represented by $W_{i,t}$, incorporate sums of rainfall and sunshine hours and means of air pressure, relative humidity, and average wind speed for each season. $Z_{i,t}$ contains two-digit industry × year fixed effects and region × year fixed effects. The inclusion of the two-digit industry × year fixed effects controls for the unobserved factors that are common to each two-digit industry in a given year, such as changes in industrial policies and production technology that are specific to a given industry. Region × year fixed effects account for common shocks occurring in a region in a given year that are the same for all firms located in that region in that year (Appendix B has a detailed definition of Chinese regions), such as trends in climate and/or changes in regional energy supply infrastructure. c_i is time-invariant firm fixed effects. Lastly, $\varepsilon_{i,t}$ are the error terms.

We then define temperature variables as a vector of temperature bins:

$$\log E_{i,t} = \sum_m \alpha_0^m Tbin_{i,t}^m + \lambda_0 W_{i,t} + \gamma Z_{i,t} + c_i + \varepsilon_{i,t} \quad (5)$$

where $Tbin_{i,t}^m$ denotes the number of days in year *t* with daily average temperatures falling into the *m*th temperature bin in the county where firm *i* is located. Daily average temperatures are measured in °C and are divided into fourteen bins, with each bin 3°C wide. $Tbin_{i,t}^1$ is defined as the number of days when daily average temperatures are below -6°C, $Tbin_{i,t}^2$ is defined as the number of days when daily average temperatures are between [-6°C, -3 °C), and so on. The last temperature bin, $Tbin_{i,t}^{14}$, is defined as the number of days when daily average temperatures are above 30°C. Because the sum of all bins equals 365,[4] we set the middle temperature bin [12°C, 15°C) as the omitted category to avoid multicollinearity. The coefficients of the other temperature bins, α_0^m, thus measure the marginal effect on $E_{i,t}$ of an additional day when daily average temperatures fall into the *m*th bin, relative to a day in the [12°C, 15°C) bin. Our main findings do not hinge on the selection of this reference bin. Other weather variables ($W_{i,t}$) and fixed effects ($Z_{i,t}$) included in Equation (5) are defined in the same way as in Equation (4).

The temperature effects on profit and the various channel variables are identified from the random variations in temperature over time. Note that the error terms $\varepsilon_{i,t}$ may be spatially and serially correlated. To account for this, we estimate standard errors that are clustered in two dimensions: within firms and within (prefecture-level) city-years (Cameron et al., 2011). Clustering standard errors within firms accounts for autocorrelation within each firm, while clustering standard errors within city-years accounts for spatial correlation across contemporary firms within each city. We also control for the heteroskedasticity of the error terms.

5. Effects of Temperature on Profit

5.1. Seasonal Average Temperatures as Temperature Variables

Column (1) of Table 1 reports the coefficient estimates of seasonal average temperature variables, which are obtained by estimating Equation (4).[5] We find that the coefficient estimate of $\text{Temp}^{\text{summer}}$ is negative and statistically significant at the 1% level, indicating that profit is negatively correlated with higher summer temperatures. Specifically, holding all else the same, a 1°C increase in $\text{Temp}^{\text{summer}}$ is associated with a reduction of 6.2% in profit. The parameter estimate of $\text{Temp}^{\text{winter}}$ is positive and statistically significant at the 1% level, suggesting that profit increases with higher winter temperatures. Holding all else the same, a 1°C increase in $\text{Temp}^{\text{winter}}$ is associated with an increase of 4.6% in profit. The effects on profit of temperature changes during the spring and fall are insignificant.

We also consider one alternative model specification that includes one-year lagged values of the weather variables as additional explanatory variables to examine whether there exist

[4] We remove weather data on February 29 in years 2000 and 2004 to ensure that the sum of temperature bins is equal to 365 during our sample period.

[5] For brevity, we report only parameter estimates of temperature variables. Parameter estimates of other weather variables are not reported and are available upon request.

lagged temperature effects on profit. Column (2) of Table 1 shows that lagged temperature changes have no effects on current year's profit. With the inclusion of lagged weather variables, the effects of $Temp^{summer}$ and $Temp^{winter}$ on profit are still statistically significant. However, their magnitudes become 29% and 20%, respectively, smaller than the coefficient estimates reported in Column (1). Based on this model specification, profit declines by 4.4% for each 1°C increase in $Temp^{summer}$ and increases by 3.7% for each 1°C increase in $Temp^{winter}$, holding all else equal.

5.2. Temperature Bins as Temperature Variables

We then estimate Equation (5) using temperature bins as temperature variables to examine the effects of temperature on profit. Figure 1 displays point estimates and the 95% confidence intervals of parameter estimates of temperature bins. The horizontal axis of this figure is temperature, while the vertical axis denotes the log profit. This figure shows an inverted-U shape for the relationship between temperature and profit. Profit increases with temperature up to 12-15°C, and then declines with higher temperatures. The negative effects on profit are particularly large when daily average temperatures are above 30°C or below -6°C. Specifically, relative to a day with an average temperature of 12-15°C, profit declines by approximately 0.8% for each additional day below -6°C or above 30°C, holding all else the same. These findings are consistent with our findings presented above when using seasonal average temperatures as temperature variables: profit increases with higher winter temperatures but declines with higher summer temperatures.

Panel A of Figure 2 shows that the inverted-U shaped relationship between temperature and profit holds when we estimate Equation (5) by incorporating one lag of the weather variables as additional explanatory variables. Estimated contemporaneous temperature effects on profit are nearly identical to those depicted in Figure 1. Panel B of Figure 2 shows lagged temperature effects on profit. Although the responses of profit to lagged temperature changes do not exhibit a clear shape, Panel B shows that temperature variations in the previous year might have affected current year's profit. This figure depicts that, relative to a day at 12-15°C, an additional day with average temperatures below -6°C or above 30°C in the previous year can reduce profit in the current year by 0.6% and 0.4%, respectively.

The critical temperature threshold identified here, [12-15°C), is consistent with the prior studies that examine the effects of temperature on global economic productivity (Burke et al., 2015) and on county-level GDP in the US (Deryugina and Hsiang, 2014). However, it is lower than that reported in Chen and Yang (2017). They find that value added per capita increases with temperature up to 21-24°C and then declines with higher temperatures.

5.3. Robustness Checks

This section checks the robustness of estimated temperature effects on profit in four scenarios. Our baseline model specification incorporates firm fixed effects, two-digit industry × year fixed effects, and region × year fixed effects. Here, we start by considering a very simple specification with only firm fixed effects and year fixed effects in Scenario (1). In this specification, year fixed effects control for shocks that are common to all firms in a given year, such as policy changes, trends in global climate, or shocks to international trade, regardless of the differences in firm characteristics and location. In Scenario (2), we incorporate firm fixed effects and region × year fixed effects, due to the concern that some shocks may vary by region. We consider these two scenarios to see whether our baseline estimates of temperature variables are sensitive to variations in model specifications. In Scenario (3), we replicate the above analyses by removing observations if profit to sales ratio is either below the 0.5% level or above the 99.5% level (rather than below the 0.1% level or above the 99.9% level in the baseline analysis) to further ensure that our results are not affected by potentially mis-specified outliers. In the baseline analysis, we construct weather variables using weather information on all days in a year, including weekdays and non-weekdays (i.e., weekends and holidays). In Scenario (4), we use weather information on weekdays only to re-construct our weather variables and replicate the above regression analyses. Sensitivity analyses are conducted by estimating Equations (4) and (5), respectively, with one lag of the weather variables. Table 2 reports coefficient estimates of seasonal temperature variables, while Figure A1 in Appendix A presents coefficient estimates of temperature bins for these scenarios.

Table 2 shows that our key finding of the negative effect of elevated summer temperatures on profit is robust across the various scenarios that we considered in this section. The negative effect on profit stemming from rising $Temp^{summer}$ ranges between 3.8% in Scenario (1) and 5.6% in Scenario (4). Effect on profit of each 1°C increase in $Temp^{winter}$ is found to be 3.4-3.9% across these scenarios, with an exception in Scenario (1), where the coefficient estimate of the $Temp^{winter}$ variable is positive but is not significant. In Scenarios (1) and (3), we find that current year's profit responds to variations in some of the seasonal temperature variables in the prior year. Specifically, profit increases with higher spring temperatures in the previous year in Scenario (1), and decreases with higher summer temperatures in the previous year in Scenario (3). These findings suggest that temperature changes in the prior year might have influenced current year's profit.

The left panels in Figure A1 in Appendix A show that the inverted-U shaped relationship between temperature and profit remains remarkably consistent across the various scenarios that we considered. The right panels in Figure A1 illustrate that temperature variations in the prior year might have affected current year's profit. This finding is consistent with our baseline finding using temperature bins as temperature variables (see Figure 2) and some of the findings using seasonal average temperatures as temperature variables (see Table 2).

6. Channels

In this section, we apply our panel methodology to explore whether temperature affects profit through the three categories of channels that we discussed in Section 2. Such analysis can provide useful information when developing efficient strategies to reduce the negative effect of temperature on profit. We present the regression results in Tables 3 and 4, by estimating Equation (4) with seasonal average temperatures as the temperature variables.[6]

6.1. Output, TFP, Labor, Capital Stock, and Investment

Table 3 reports the estimated impacts of temperature on output and several key elements directly affecting output, including TFP, labor, capital stock and investment. Column (1) of Table 3 shows a large and negative effect of elevated $Temp^{summer}$ on output. Holding all else the same, a 1°C increase in $Temp^{summer}$ is associated with a reduction of 7.2% in output. This finding is consistent with several prior studies discovering that industrial output declines with higher summer temperatures (Burke et al., 2015; Chen and Yang, 2017; Dell et al., 2012; Hsiang, 2010). Similarly to the relationship between $Temp^{winter}$ and profit, output increases with higher $Temp^{winter}$. Specifically, a 1°C higher $Temp^{winter}$ is associated with an increase of 2.7% in output. Output does not exhibit significant responses to changes in $Temp^{spring}$ and $Temp^{fall}$.

The negative impact of higher $Temp^{summer}$ on output mainly stems from the negative responses of TFP, investment, and capital stock to higher $Temp^{summer}$. Column (2) of Table 3 shows a negative impact of higher $Temp^{summer}$ on TFP. Specifically, a 1°C higher $Temp^{summer}$ is associated with 5.2% lower TFP. In a related paper, Zhang et al. (2018) also find a negative effect of high temperatures on TFP. The negative effect of $Temp^{summer}$ on TFP may stem from the negative effects of higher $Temp^{summer}$ on labor and capital productivities (Mostafavi and Agnew, 1996; Zivin and Neidell, 2014). Similarly to Zhang et al. (2018), the result on labor in Column (3) of Table 3 suggests that higher $Temp^{summer}$ has very limited impact on the number of workers used for industrial production. Contrary to the finding presented in Zhang et al. (2018), Column (4) of Table 3 reports a negative and significant impact of $Temp^{summer}$ on capital stock.

[6] Adding one lag of weather variables as additional explanatory variables produces broadly similar results; see Tables A2 and A3 in Appendix A. For brevity, when examining the temperature effects on the various channel variables and heterogeneous temperature effects in the next section, we estimate Equation (4) only and do not use temperature bins as temperature variables.

Holding all else the same, a 1°C increase in $Temp^{summer}$ reduces capital stock by 3.2%. That is the case because higher $Temp^{summer}$ reduces industrial firms' investment (see Column (5) of Table 3), which in turn decreases capital stock. Investment declines with higher $Temp^{summer}$, possibly because higher $Temp^{summer}$ can affect investment behavior (Cao and Wei, 2005). Holding all else the same, a 1°C higher summer temperature is associated with 4.1% lower investment.

We find that TFP, capital stock, and investment increase with higher $Temp^{winter}$. Holding all else the same, a 1°C increase in $Temp^{winter}$ raises TFP, capital stock, and investment by 2.4%, 1.4% and 4.1%, respectively. Column (3) of Table 3 shows that the number of workers employed declines with higher $Temp^{spring}$. One possible explanation for this finding is that, when spring becomes pleasantly temperate, it might be suitable for crop planting and cause workers from rural China to stay in their rural homes for crop production, resulting in reduced labor supply in manufacturing firms. $Temp^{fall}$ has no effects on TFP, labor, capital stock, or investment.

6.2. Labor Costs

High temperatures may also impact labor costs, as the Chinese government requires that employers pay high-temperature subsidies to workers when daily T_{max} is above 35°C. When examining the impact of temperature on labor costs, we use the number of days with daily T_{max} above 35°C in summer as the only temperature variable, while incorporating our standard control specified in Equation (4). Column (1) of Table 4 reports a positive and significant impact of high temperatures on labor costs. Holding all else the same, an additional day with daily T_{max} above 35°C is associated with a 1.3% increase in labor costs. This finding holds with an alternative model specification that incorporates one lag of weather variables as additional explanatory variables (see Table A3 in Appendix A).

6.3. Inventory and Innovation Activity

In the conceptual framework, we hypothesize that temperature may impact firm inventory levels by influencing the performance of drivers and vehicles. Looking at Column (2) of Table 4, we find that seasonal average temperatures have no effects on inventory.

Temperature may also affect firms' innovation activity when high temperatures reduce labor productivity. This is because firms may reduce R&D spending and instead use limited resources to undertake costly defensive actions in mitigating the negative effect of rising temperatures on labor productivity. R&D spending is a good indicator of a firm's innovation activity. Here, following Jefferson (2003) and Lin et al. (2011), we use the ratio of new product sales to a firm's total industrial output value to measure that firm's innovation activity. We choose this approach for two reasons. First, the original firm-level data set contains firms' R&D spending only for four years and has many zero values for this variable. Second, manufacturing firms differ substantially in size across industries, regions and ownership types. Thus, we believe that the ratio of new product sales to the total industrial output value is a better proxy for firms' innovation activity than the value of new product sales alone.

Column (3) of Table 4 shows a negative but statistically insignificant relationship between $Temp^{summer}$ and innovation activity. The relationship becomes statistically significant at the 10% level when we add one lag of weather variables (see Column (3) of Table A3 in Appendix A). We find a negative and significant relationship between lagged $Temp^{summer}$ and the innovation variable. Specifically, a 1°C increase in $Temp^{summer}$ in the previous year reduces the current year's innovation activity by 0.3%. This is a reasonable finding, because it usually takes a long period time for firms to get returns from their R&D activity. Combined, these results suggest that higher summer temperatures may have negatively affected firms' innovation activity, which in turn has generated a negative impact on profit.

7. Heterogeneous Temperature Effects

The temperature effects on profit and the various channel variables presented above may differ across regions, ownership types, and industries. For instance, some regions may have already undertaken actions to mitigate the negative impacts of thermal stress on workers and machines. Compared to privately- and collectively-owned domestic firms, foreign firms and SOEs are likely to take better protective measures, such as running air conditioners during hot days and/or providing high-temperature subsidies to workers. The temperature effects may also differ by industry due to the differences in exposure to high temperatures, as production for some industries primarily occurs indoors. In this section, we explore the heterogeneity in temperature effects across regions, ownership types, and industries, by estimating Equation (4) with one lag of the weather variables.

7.1. Heterogeneous Temperature Effects by Region

Figure 3 displays the contemporaneous summer temperature effects on profit and the various channel variables by region (Appendix B shows the provinces included in each of the six traditional Chinese regions). We present the summer temperature effects, because the effect of higher summer temperatures on profit based on the full sample is negative and statistically significant. To facilitate comparison, we add the baseline results based on the full sample in Figure 3.

We find substantial differences in estimated temperature impacts across regions. Firms located in East China are most affected by higher summer temperatures, with profit declining by 9.0% for each 1°C increase in $Temp^{summer}$, holding all else the same. Further investigation indicates that, by negatively affecting TFP (-6.1%/1°C), capital stock (-4.6%/1°C), and investment (-6.4%/1°C) in East China, a 1°C increase in $Temp^{summer}$ is associated with a reduction in output by 8.6%, which in turn results in the negative response of profit to higher $Temp^{summer}$ in that region.

The relationships between $Temp^{summer}$ and profit in Northeast and South Central China are also negative, although they are insignificant. The negative profit-temperature relationship in Northeast China is mainly driven by the negative response of output to higher $Temp^{summer}$ (-9.6%/1°C), which results from the adverse effect of higher $Temp^{summer}$ on TFP (-10.4%/1°C). The negative profit-temperature relationship in South Central China stems from two sources, including the negative impacts of higher $Temp^{summer}$ on output (-6.5%/1°C) and on innovation activity (-0.9%/1°C). The negative impacts of higher $Temp^{summer}$ on capital stock (-7.1%/1°C) and investment (-15.5/1°C) are the two key factors driving the negative response of output to higher $Temp^{summer}$ in South Central China. Moreover, although $Temp^{summer}$ did not exert significant impacts on profit for firms located in North China and Southwest China, we find that higher $Temp^{summer}$ leads to an increase in labor costs (+0.4%/1°C) in Southwest China and raises firms' inventory levels in North China (+10.5%/1°C). Consistent with our full-sample analysis, the responses of labor to temperature changes in the regional analyses are either insignificant or exhibit low levels of statistical significance.

7.2. Heterogeneous Temperature Effects by Ownership

Figure 4 displays the estimated summer temperature effects on profit and the channel variables by ownership. We find that private firms are most influenced by higher summer temperatures, while the effects of higher $Temp^{summer}$ on profit for firms with other types of ownership are insignificant. Holding all else equal, private firms' profit declines by 4.7% for each 1°C increase in $Temp^{summer}$. This negative profit-temperature relationship is mainly because higher $Temp^{summer}$ raises labor costs (+0.2%/1°C) and reduces output (-7.1%/1°C) by lowering TFP (-5.7%/1°C).

The responses of profit to higher $Temp^{summer}$ are also negative for SOEs and collectively owned firms, although they are not statistically significant. The negative correlation between profit and $Temp^{summer}$ for SOEs is due to the adverse impact of higher $Temp^{summer}$ on output (-2.5%/1°C) and the positive impact of higher $Temp^{summer}$ on labor costs (+0.1%/1°C). We find that a 1°C increase in $Temp^{summer}$ is associated with a reduction of 2.4% in capital stock, which is the leading reason behind the output reduction for SOEs. Output also deceases with higher $Temp^{summer}$ for collectively owned firms. Specifically, a 1°C increase in $Temp^{summer}$ is associated with a reduction of 7.7% in output for collectively owned firms, which is mainly due to the negative $Temp^{summer}$ effects on TFP (-5.9%/1°C) and capital stock (-3.7%/1°C).

Across the various types of ownership that we considered, we find that foreign firms are least affected by higher $Temp^{summer}$. In contrast to the negative temperature effects on SOEs, private and collective firms, the effect of higher $Temp^{summer}$ on foreign firms' profit is slightly positive, although it is insignificant. This is an expected outcome because foreign firms in China usually face stringent environmental and labor regulations. Possibly by installing air conditioners and taking other protective measures, foreign firms have minimized the adverse impacts of high temperatures. As a result, output and other channel variables exhibit insignificant responsiveness to higher $Temp^{summer}$.

7.3. Heterogeneous Temperature Effects by Industry

Figure 5 shows the estimated summer temperature effects on profit for each of the 39 two-digit industries.[7] We find substantial heterogeneity in the estimated temperature effects on profit across industries. Among the 39 two-digit industries that we considered, special equipment manufacturing, stationary, and furniture are the three industries affected most by higher $Temp^{summer}$. For each 1°C increase in $Temp^{summer}$, profit in the three industries declines by 10.5%, 12.7% and 13.8%, respectively. Because production in the three industries occurs mostly indoors, this finding suggests limited adaptation undertaken by these industries to cope with high summer temperatures. Higher $Temp^{summer}$ also leads to substantial profit losses in outdoor industries, such as fabricated metal products and rubber.

The channels by which temperature affects profit differ across industries. For instance, the profit losses for the electrical machinery and equipment manufacturing industries are mainly due to the negative temperature effects on TFP and capital stock, and thus on output. The main channels by which temperature reduces profit for the furniture industry are through the negative effects of higher $Temp^{summer}$ on TFP, and thus output, and the positive effect of higher $Temp^{summer}$ on labor costs. In addition to the negative effect of $Temp^{summer}$ on output, higher $Temp^{summer}$ reduces profit in the plastics industry because higher $Temp^{summer}$ raises inventory levels. Reduced innovation activity due to higher summer temperatures is one of the main causes of the negative $Temp^{summer}$ effect on profit in the food processing industry.

[7] In Figure 5, we exclude two industries with less than 1,000 observations, including oil and gas exploration and other mining sectors.

8. Impacts of Future Climate Change

In this section, we quantify the potential impact of future warming on profit. We obtain projections of future climate variables from ClimateWizard (http://www.climatewizard.org/). This website provides monthly average temperature and monthly total rainfall for the medium term (mid-century, 2050s) and the long term (end-century, 2080s), based on the most recent global climate models under three warming scenarios: the B1, the A1B and the A2 scenarios. The three scenarios describe low, medium and high rates of warming, respectively, by the end of this century. We take the climate projections under the three warming scenarios based on the widely-used global climate model UKMO-HadCM3 developed by the UK Meteorological Office (https://www.metoffice.gov.uk/). We download the data at 50 km spatial resolution, enabling us to obtain future climate variables for all Chinese counties included in our sample. We project the impact of future warming on profit for the medium term only, because firms may undertake various adaptation actions in the long term in response to global warming and our parameter estimates based on short-term observations cannot capture this long-term adaptation.

We use the following steps to obtain the impact of future warming on profit. First, we compute the projected changes in seasonal average temperatures for all counties in our sample, which are the differences between the projected seasonal average temperatures based on the ClimateWizard database and the mean temperatures in our sample. Second, we multiply the projected changes in seasonal average temperatures by point estimates of the sum of the contemporaneous and one-year lagged marginal effects of seasonal average temperatures on profit to compute predicted changes in profit for all firms. Lastly, we weight firm-specific changes in profit by their shares in industrial output over the sample period,[8] to obtain the estimates of the impact of future warming on profit.

Table 5 presents the impacts of future warming on profit by 2050. We find that, across the various scenarios that we considered, firms' profit is projected to decline annually by 2.6-4.2% under the A2 scenario, 2.5-9.2% under the A1B scenario, and 3.0-5.6% under the B1 scenario during the mid-21st century. In 2007, the total profit produced by Chinese manufacturing firms was approximately CNY 1180 billion. These projected profit losses due to future warming are, therefore, equivalent to CNY 30.7-49.6 billion under the A2 scenario, CNY 29.5-108.6 billion under the A1B scenario, and CNY 35.4-66.1 billion under the B1 scenario in 2007 values.

[8] In the data set, we find that some firms have large output, but they make small profits. To reflect the effect of firm size on projected impacts of future warming on profit, we use the share of a firm's output in total output as the weighting variable.

The main causes of future profit losses are due to the projected reductions in output and firms' innovation activity. Table 6 reports the effects of future warming on output and innovation activity,[9] which are computed based on the sum of the contemporaneous and one-year lagged marginal effects of seasonal average temperatures obtained in the baseline scenario (reported in Tables A2 and A3). We find that output is projected to decline across the three warming scenarios during the mid-21st century, ranging from 8.7% under the B1 scenario to 17.5% under the A1B scenario. Firms' innovation activity is also projected to decrease by 2050 due to future warming, by 0.5% under the A2 scenario, 1.1% under the A1B scenario, and 0.4% under the B1 scenario.

9. Conclusions and Discussion

Using a rich firm-level data set of Chinese manufacturing firms, combined with a fine-scale daily weather data set, this paper examines the relationship between temperature and profit and illustrates the mechanisms through which temperature affects profit. This is the first firm-level analysis estimating the link between temperature and profit. We find nonlinear responses of profit to temperature changes. A 1°C increase in average summer temperatures reduces firms' profit by 3.8-6.2%, and this estimate remains robust across a variety of alternative specifications, estimation approaches, and samples. A 1°C increase in average winter temperatures is associated with an increase of 3.4-4.6% in profit, but the estimate is less robust. When using temperature bins to denote the relationship between temperature and profit, we find that profit increases linearly with temperature up to 12-15°C and then declines sharply with higher temperatures.

Our further investigation reveals that higher temperatures affect profit through a number of channels. By negatively affecting TFP, investment, and capital stock, a 1°C increase in average summer temperatures is associated with a reduction of 7.2% in industrial output. This finding is consistent with prior studies documenting the negative relationship between temperature and industrial output (Burke et al., 2015; Chen and Yang, 2017; Dell et al., 2012; Hsiang, 2010). Higher summer temperatures also lead to a modest increase in labor costs, possibly due to the provision of high-temperature subsidies to workers during extremely hot days. Furthermore, we find that firms' innovation activity also declines with higher summer temperatures.

We find substantial heterogeneity in the effects of temperature on profit across regions, ownership types and industries. Higher summer temperatures exert large and significant negative

[9] We cannot project the impact of future warming on labor costs, because ClimateWizard does not provide projected daily/monthly maximum temperatures.

impacts on profit for industrial firms located in East China, whereas the temperature-profit relationships are insignificant for firms in other regions. Private enterprises are most impacted by higher summer temperatures, while the temperature effects are insignificant for foreign firms and SOEs. Both indoor and outdoor industries are negatively affected by higher temperatures, suggesting limited adaptation undertaken by Chinese manufacturing firms to cope with higher temperatures. As a result, the total profit of Chinese manufacturing firms is projected to decline annually by 2.5-9.2% (or CNY 29.5-108.6 billion in 2007 values) by 2050 under warming scenarios provided by the global climate model UKMO-HadCM3.

These results have several policy implications. First, climate adaptation polices focusing on the Chinese manufacturing sector should prioritize developing strategies to reduce the adverse impacts of high temperatures on output. In particular, these strategies should minimize the negative responsiveness of TFP, investment, and capital stock to high temperatures. Second, stringent enforcement of labor regulations in privately and collectively owned firms can help mitigate the damages to the Chinese manufacturing sector due to high temperatures. Third, the development of efficient strategies to cope with future warming should consider heterogeneity in the effects of temperature across regions, ownership types, and industries.

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Tables and Figures

Table 1. Effects of Temperature on Profit (dependent variable is log profit)

	(1)	(2)
$Temp^{spring}$	-0.0031	-0.0073
	(0.0156)	(0.0146)
$Temp^{summer}$	-0.0623***	-0.0440***
	(0.0164)	(0.0156)
$Temp^{fall}$	-0.0085	0.0040
	(0.0143)	(0.0149)
$Temp^{winter}$	0.0457***	0.0371***
	(0.0121)	(0.0117)
$L.Temp^{spring}$		0.0048
		(0.0142)
$L.Temp^{summer}$		-0.0184
		(0.0162)
$L.Temp^{fall}$		0.0077
		(0.0136)
$L.Temp^{winter}$		0.0166
		(0.0128)
Observations	1,347,937	1,346,511
R^2	0.7766	0.7771

Notes: This table shows estimated temperature effects on profit. Column (1) shows the contemporaneous effects of seasonal average temperatures on profit. Column (2) shows the contemporaneous and one-year lagged temperature effects on profit. These coefficient estimates are obtained by estimating Equation (4) and including rainfall, sunshine hours, air pressure, relative humidity, and average wind speed as additional weather variables. The two regressions include firm fixed effects, two-digit industry × year fixed effects, and region × year fixed effects. Standard errors, shown in parentheses, are clustered within firms and within prefecture-level city-years. Units for explanatory variables: 1°C for temperature. ***p<0.01, ** p<0.05, p<0.1

Table 2. Robustness Checks (dependent variable is log profit)

	Scenario (1)	Scenario (2)	Scenario (3)	Scenario (4)
	Firm fixed effects and year fixed effects only	Firm fixed effects and region × year fixed effects	Dropping observations with a stringent criterion on profit to sales ratio	Weather information on weekdays only
	(1)	(2)	(3)	(4)
$Temp^{spring}$	0.0219*	0.0026	-0.0158	0.0151
	(0.0130)	(0.0156)	(0.0134)	(0.0138)
$Temp^{summer}$	-0.0377**	-0.0470***	-0.0508***	-0.0557***
	(0.0154)	(0.0164)	(0.0139)	(0.0154)
$Temp^{fall}$	0.0047	0.0016	0.0133	0.0093
	(0.0131)	(0.0156)	(0.0136)	(0.0150)
$Temp^{winter}$	0.0006	0.0386***	0.0392***	0.0336***
	(0.0097)	(0.0125)	(0.0110)	(0.0118)
L1: $Temp^{spring}$	0.0835***	0.0150	0.0019	0.0051
	(0.0139)	(0.0152)	(0.0130)	(0.0132)
L1: $Temp^{summer}$	-0.0242	-0.0216	-0.0300**	-0.0122
	(0.0159)	(0.0167)	(0.0145)	(0.0156)
L1: $Temp^{fall}$	0.0025	0.0082	0.0059	-0.0235*
	(0.0125)	(0.0141)	(0.0123)	(0.0136)
L1: $Temp^{winter}$	0.0070	0.0114	0.0230*	0.0242*
	(0.0109)	(0.0137)	(0.0121)	(0.0131)
Observations	1,346,511	1,346,511	1,205,668	1,346,511
R^2	0.7734	0.7747	0.8007	0.7770

Notes: This table shows the contemporaneous and one-year lagged temperature effects on profit in Scenarios (1)-(4) considered in the robustness check section. Column (1) shows the regression results with firm and year fixed effects only. Column (2) shows the regression results with firm and region × year fixed effects. Column (3) shows the regression results by removing observations if profit to sales ratio is either below the 0.5% level or above the 99.5% level. Column (4) shows the regression results from using weather information on weekdays only. All scenarios include temperature, rainfall, sunshine hours, rainfall, air pressure, relative humidity, and average wind speed as weather variables and incorporate firm fixed effects, two-digit industry × year fixed effects, and region × year fixed effects, unless otherwise noted. Standard errors, shown in parentheses, are clustered within firms and within prefecture-level city-years. Units for explanatory variables: 1°C for temperature. ***p<0.01, ** p<0.05, p<0.1

Table 3. Temperature Effects on Output, TFP, Labor, Capital Stock and Investment

	log(output)	log(TFP)	log(labor)	log(capital stock)	log(investment)
	(1)	(2)	(3)	(4)	(5)
$Temp^{spring}$	-0.0033	-0.0036	-0.0222***	0.0011	-0.0268
	(0.0099)	(0.0089)	(0.0045)	(0.0067)	(0.0194)
$Temp^{summer}$	-0.0724***	-0.0518***	-0.0054	-0.0322***	-0.0408**
	(0.0091)	(0.0086)	(0.0052)	(0.0073)	(0.0207)
$Temp^{fall}$	0.0008	-0.0006	0.0084	-0.0005	0.0242
	(0.0087)	(0.0079)	(0.0076)	(0.0074)	(0.0192)
$Temp^{winter}$	0.0265***	0.0239***	-0.0049	0.0141***	0.0411***
	(0.0072)	(0.0070)	(0.0043)	(0.0054)	(0.0154)
Observations	1,347,937	1,346,459	1,347,937	1,345,060	634,902
R^2	0.8304	0.6987	0.9002	0.8941	0.6433

Notes: This table shows estimated effects of seasonal average temperatures on output, TFP, labor, capital stock and investment. These coefficient estimates are obtained by estimating Equation (4) and including rainfall, sunshine hours, air pressure, relative humidity, and average wind speed as additional weather variables. These regressions include firm fixed effects, two-digit industry × year fixed effects, and region × year fixed effects, without incorporating lagged weather variables. Standard errors, shown in parentheses, are clustered within firms and within prefecture-level city-years. The original data set contains a large number of missing values for capital depreciation, which is used to compute investment, thus resulting in smaller observations in the regression in Column (5) relative to other regression analyses. Units for explanatory variables: 1°C for temperature. ***p<0.01, ** p<0.05, p<0.1

Table 4. Temperature Effects on Labor Costs, Inventory and Innovation Activity

	log(labor costs)	log(inventory)	Innovation activity (measured by ratio of new product sales to the total industrial output value)
	(1)	(2)	(3)
Number of days with T_{max}>= 35°C	0.0013**		
	(0.0006)		
$Temp^{spring}$		-0.0093	-0.0040***
		(0.0136)	(0.0011)
$Temp^{summer}$		0.0046	-0.0021
		(0.0120)	(0.0013)
$Temp^{fall}$		-0.0108	0.0013
		(0.0113)	(0.0011)
$Temp^{winter}$		0.0165	0.0001
		(0.0107)	(0.0010)
Observations	1,345,289	1,347,838	1,166,394
R^2	0.8676	0.7485	0.6427

Notes: This table shows estimated temperature effects on labor costs, inventory and innovation activity, measured by the ratio of new product sales to the total industrial output value. Column (1) show the estimated temperature effect on labor costs, which is obtained by estimating Equation (4) and using the number of days with daily T_{max} above 35°C as the only temperature variable. Columns (2) and (3) show the estimated temperature effects on firms' inventory and innovation activity. These coefficient estimates are obtained by estimating Equation (4) and using seasonal average temperatures as temperature variables. All regressions include rainfall, sunshine hours, air pressure, relative humidity, and average wind speed as additional weather variables, and incorporate firm fixed effects, two-digit industry × year fixed effects, and region × year fixed effects. Lagged weather variables are not incorporated. Standard errors, shown in parentheses, are clustered within firms and within prefecture-level city-years. Units for explanatory variables: 1°C for temperature. ***p<0.01, ** p<0.05, p<0.1

Table 5. Effects of Warming on Profit Under Different Warming Scenarios by 2050s (%)

	Baseline	Scenario (1)	Scenario (2)	Scenario (3)	Scenario (4)
	Baseline scenario	Firm fixed effects and year fixed effects only	Firm fixed effects and region × year fixed effects	Dropping observations with a stringent criterion on profit to sales ratio	Weather information on weekdays only
	(1)	(2)	(3)	(4)	(5)
the A2 scenario	-2.62	-2.72	-3.96	-4.19	-2.89
the A1B scenario	-6.49	-2.45	-8.28	-9.18	-7.09
the B1 scenario	-4.12	-2.99	-4.95	-5.58	-4.48

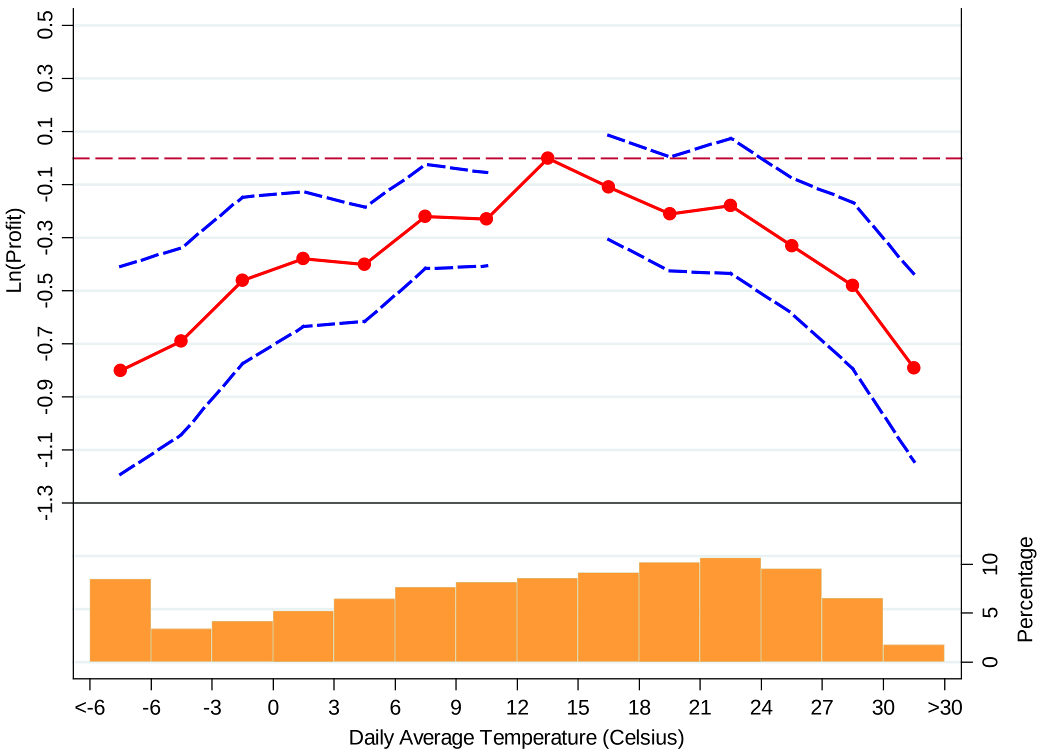
Notes: This table reports projected impacts of future warming on profit in percentage terms under three warming scenarios (the B1, A1B and A2 scenarios) in the medium term (2050s) under the climate model UKMO-HadCM3. Column (1) reports the projections based on the coefficient estimates obtained in the baseline scenario. Columns (2)-(5) report the projections based on the coefficient estimates obtained in the robustness check section.

Table 6. Effects of Warming on Output and Innovation Activity

	Output	Innovation Activity
the A2 scenario	-11.10	-0.53
the A1B scenario	-17.46	-1.13
the B1 scenario	-8.72	-0.40

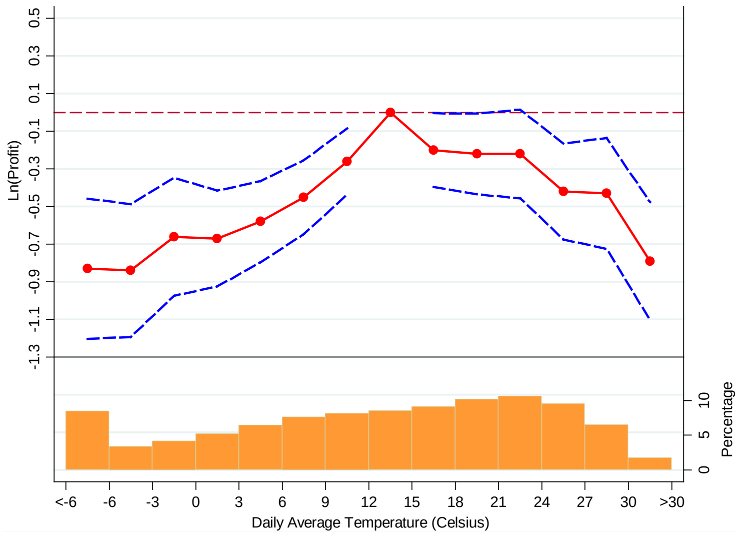
Notes: This table reports projected impacts of future warming in percentage terms under three warming scenarios (the B1, A1B and A2 scenarios) in the medium term (2050s) under the climate model UKMO-HadCM3. Innovation activity is measured by the ratio of new product sales to the total industrial output value.

Figure 1. Nonlinear Relationship between Temperature and Profit

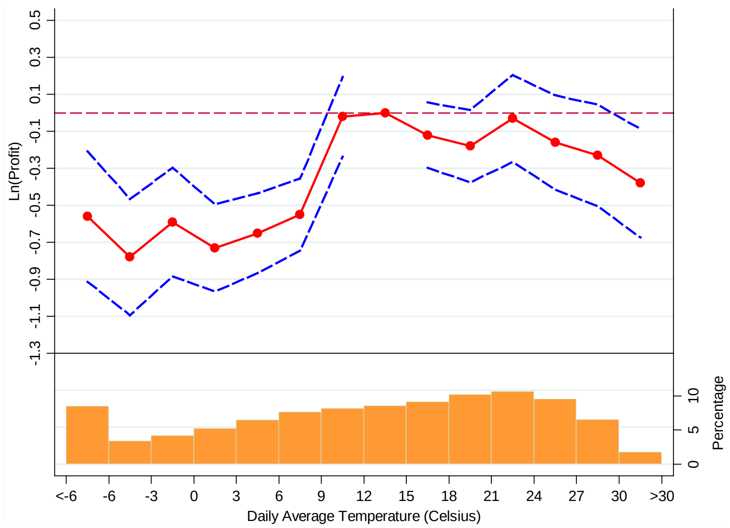


Notes: This figure displays the effect of daily average temperature on log profit in percentage terms. The red curve represents point estimates of temperature bins, while the 95% confidence bands are added as blue dashed lines. Histograms at the bottom show the percentage distribution of each temperature bin in the sample.

Figure 2. Nonlinear Relationship between Temperature and Profit with One Lag of Weather Variables



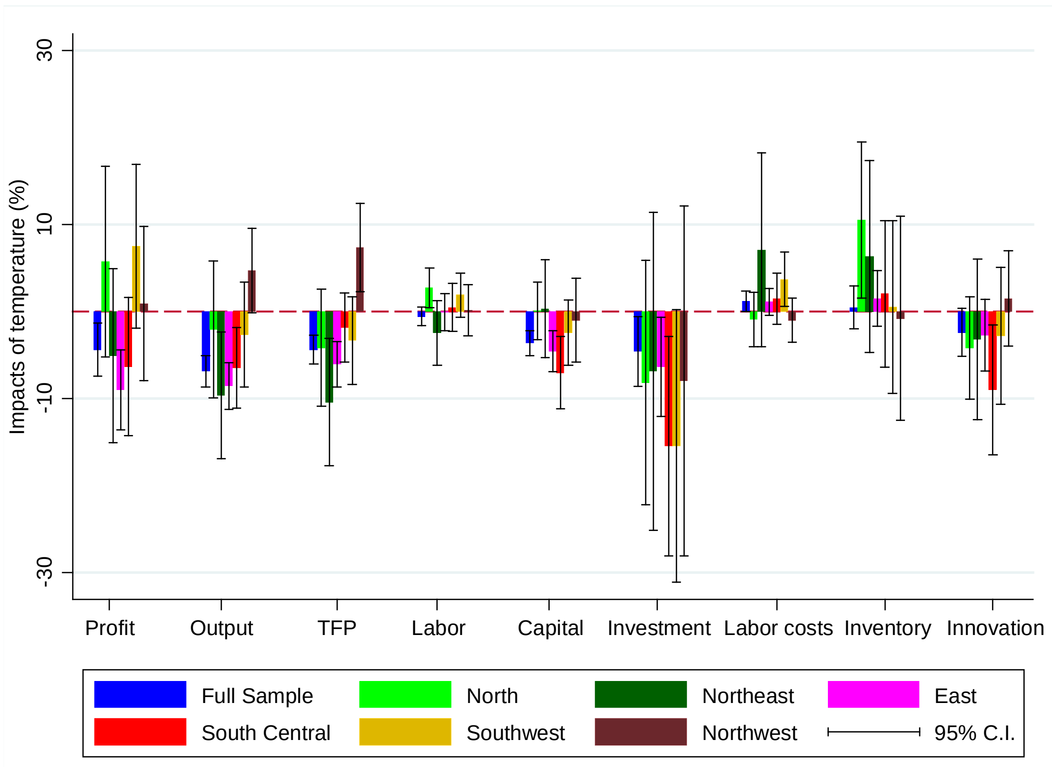
(A) Contemporaneous temperature effects



(B) Lagged temperature effects

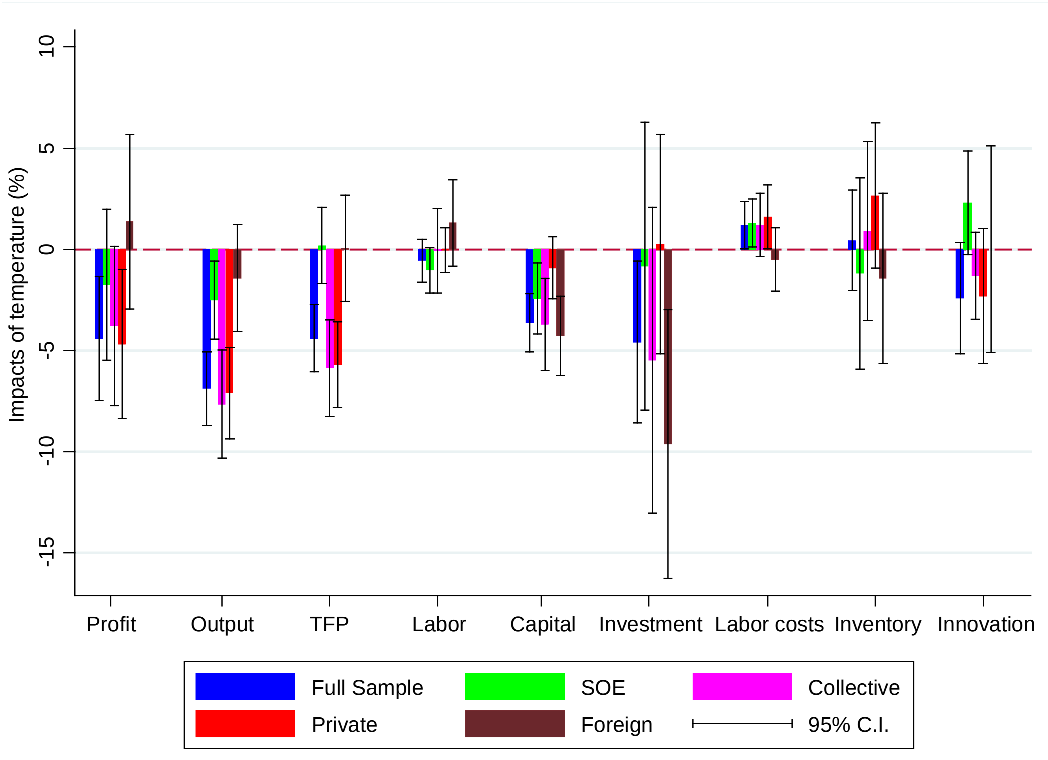
Notes: The two figures display the effect of daily average temperature on log profit in percentage terms. Panel (A) shows the contemporaneous effects of daily average temperature on profit, while Panel (B) shows the lagged temperature effects on profit. The red curve in each panel represents point estimates of temperature bins, while the 95% confidence bands are added as blue dashed lines. Histograms at the bottom in each panel show the percentage distribution of each temperature bin in the sample.

Figure 3. Heterogeneous Temperature Effects by Region



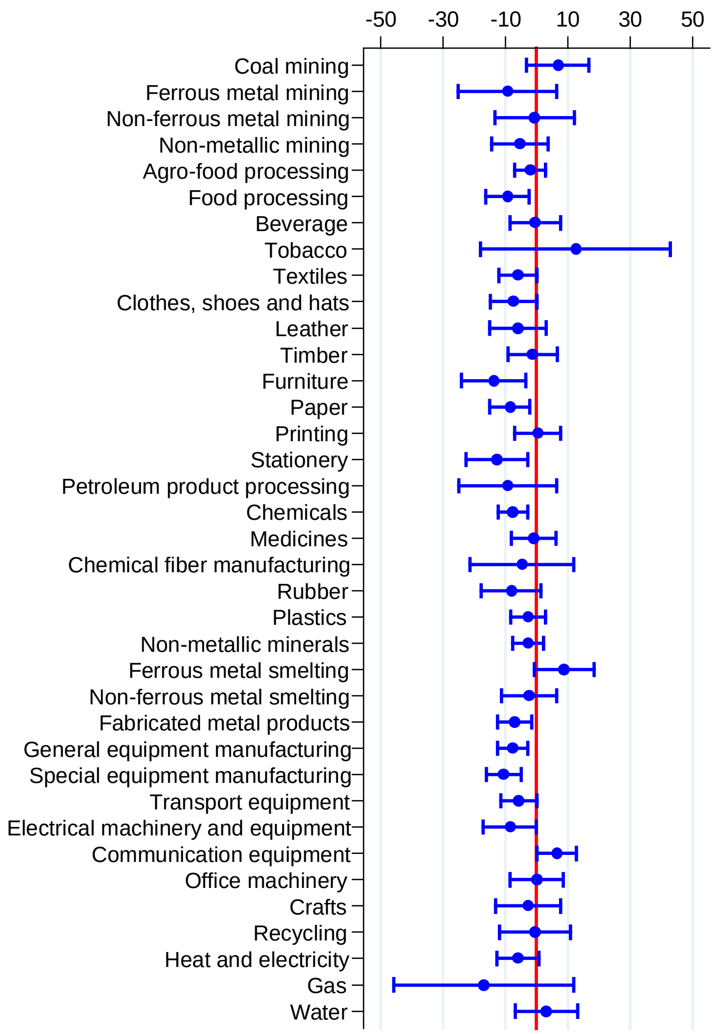
Notes: This figure shows the contemporaneous impacts of higher summer temperatures on profit and the various channel variables in percentage terms. Each cluster shows the impacts on a given variable, varied by region. Black lines denote 95% confidence bands. For ease of illustration, coefficient estimates of the temperature variables for labor costs and innovation are multiplied by 10. Regression results are obtained by estimating Equation (4) and incorporating one lag of the weather variables as additional explanatory variables. Standard errors are clustered within firms and within prefecture-level city-years. Estimated coefficients of temperature variables are interpreted as the percentage changes with a 1°C increase in average summer temperatures.

Figure 4. Heterogeneous Temperature Effects by Ownership



Notes: This figure shows the contemporaneous impacts of higher summer temperatures on profit and the various channel variables in percentage terms. Each cluster shows the impacts on a given variable, varied by ownership. Black lines denote 95% confidence bands. For ease of illustration, coefficient estimates of the temperature variables for labor costs and innovation are multiplied by 10. Regression results are obtained by estimating Equation (4) and incorporating one lag of the weather variables as additional explanatory variables. Standard errors are clustered within firms and within prefecture-level city-years. Estimated coefficients of temperature variables are interpreted as the percentage changes with a 1°C increase in average summer temperatures.

Figure 5. Heterogeneous Temperature Effects on Profit across Industries (%)



Notes: This figure shows the contemporaneous impacts of higher summer temperatures on profit in percentage terms. Blue dots represent point estimates and blue bars denote the 95% confidence bands. Results displayed here are obtained by estimating Equation (4) and incorporating one lag of the weather variables as additional explanatory variables. Standard errors are clustered within firms and within prefecture-level city-years. Estimated coefficients of temperature variables are interpreted as the percentage changes with a 1°C increase in average summer temperatures.

Appendix A: Additional Tables and Figures

Table A1. Summary Statistics

Variable	Unit	Observation	Mean	Std. Dev.	Min	Max
Log (profit)	-	1347937	6.611	1.790	0.000	13.636
Log (output)	-	1347937	8.786	1.254	4.745	12.477
Log (TFP)	-	1346459	3.331	0.903	-3.294	10.043
Log (labor)	-	1347937	4.766	1.069	2.079	11.982
Log (capital stock)	-	1345060	8.402	1.611	0	15.987
Log (investment)	-	634902	6.643	2.216	0	15.358
Log (labor costs)	-	1345289	7.132	1.230	0	13.790
Log (inventory)	-	1347838	7.145	2.324	0	14.599
Ratio of new product sales to the total industrial output value	-	1166394	0.031	0.141	0	1
$Temp^{spring}$	°C	1347937	16.085	3.562	-6.243	27.822
$Temp^{summer}$	°C	1347937	26.486	2.286	4.939	32.757
$Temp^{fall}$	°C	1347937	17.676	4.336	-6.508	27.636
$Temp^{winter}$	°C	1347937	5.070	6.505	-28.789	23.568
$Rain^{spring}$	cm	1347937	27.188	19.445	0.000	180.530
$Rain^{summer}$	cm	1347937	50.328	25.222	0.030	253.860
$Rain^{fall}$	cm	1347937	19.114	12.464	0.000	146.350
$Rain^{winter}$	cm	1347937	11.936	9.849	0.000	51.260
$Sunshine^{spring}$	10 hours	1347937	50.935	16.472	0.000	100.950
$Sunshine^{summer}$	10 hours	1347937	56.332	10.714	0.000	110.380
$Sunshine^{fall}$	10 hours	1347937	48.761	10.954	0.000	92.320
$Sunshine^{winter}$	10 hours	1347937	37.998	12.091	2.440	86.420
Air $pressure^{spring}$	hPa	1347937	996.698	38.941	572.419	1016.534
Air $pressure^{summer}$	hPa	1347937	988.598	37.528	575.836	1007.650
Air $pressure^{fall}$	hPa	1347937	1000.543	38.702	576.057	1021.827
Air $pressure^{winter}$	hPa	1347937	1007.009	40.462	569.223	1029.635
$Humidity^{spring}$	%	1347937	67.580	11.946	18.239	91.630
$Humidity^{summer}$	%	1347937	75.777	6.672	22.022	95.522
$Humidity^{fall}$	%	1347937	71.558	6.955	24.506	92.846
$Humidity^{winter}$	%	1347937	69.223	9.230	14.667	90.422
Wind $speed^{spring}$	m/s	1347937	2.654	0.951	0.010	11.307
Wind $speed^{summer}$	m/s	1347937	2.365	0.823	0.188	11.615
Wind $speed^{fall}$	m/s	1347937	2.248	0.931	0.097	8.443
Wind $speed^{winter}$	m/s	1347937	2.355	0.983	0.110	8.558

Notes: This table shows summary statistics on our key variables of interest in logs and seasonal weather variables over the period 1998-2007. Unit of observation is a firm-year.

Table A2. Temperature Effects on Output, TFP, Labor, Capital Stock and Investment

	log(output)	log(TFP)	log(labor)	log(capital stock)	log(investment)
	(1)	(2)	(3)	(4)	(5)
$Temp^{spring}$	-0.0061	-0.0027	0.0274***	-0.0001	-0.0307
	(0.0095)	(0.0085)	(0.0048)	(0.0066)	0.0192)
$Temp^{summer}$	-0.0688***	-0.0439***	-0.0056	-0.0362***	-0.0458**
	(0.0093)	(0.0085)	(0.0054)	(0.0073)	(0.0204)
$Temp^{fall}$	0.0179*	0.0087	0.0082	0.0098	0.0353*
	(0.0094)	(0.0083)	(0.0060)	(0.0075)	(0.0199)
$Temp^{winter}$	0.0216***	0.0193***	-0.0014	0.0084	0.0266*
	(0.0073)	(0.0069)	(0.0046)	(0.0059)	(0.0156)
$L.Temp^{spring}$	0.0067	0.0011	-0.0056	0.0010	-0.0037
	(0.0091)	(0.0080)	(0.0050)	(0.0068)	(0.0193)
$L.Temp^{summer}$	-0.0439***	-0.0229**	-0.0149**	-0.0176**	-0.0258
	(0.0095)	(0.0093)	(0.0073)	(0.0079)	(0.0189)
$L.Temp^{fall}$	0.0219**	0.0138	0.0002	0.0127*	0.0040
	(0.0085)	(0.0084)	(0.0069)	(0.0065)	(0.0180)
$L.Temp^{winter}$	-0.0057	0.0052	0.0070*	-0.0187***	-0.0121
	(0.0082)	(0.0073)	(0.0041)	(0.0059)	(0.0156)
Observations	1,346,511	1,345,055	1,346,511	1,343,647	634,232
R-squared	0.8308	0.6994	0.9004	0.8942	0.6437

Notes: This table shows estimated effects of seasonal average temperatures on output, TFP, labor, capital stock and investment. These coefficient estimates are obtained by estimating Equation (4) and including rainfall, sunshine hours, air pressure, relative humidity, and average wind speed as additional weather variables. These regressions include firm fixed effects, two-digit industry × year fixed effects, and region × year fixed effects, while incorporating one lag of weather variables as additional explanatory variables. Standard errors, shown in parentheses, are clustered within firms and within prefecture-level city-years. Units for explanatory variables: 1°C for temperature. ***p<0.01, ** p<0.05, p<0.1

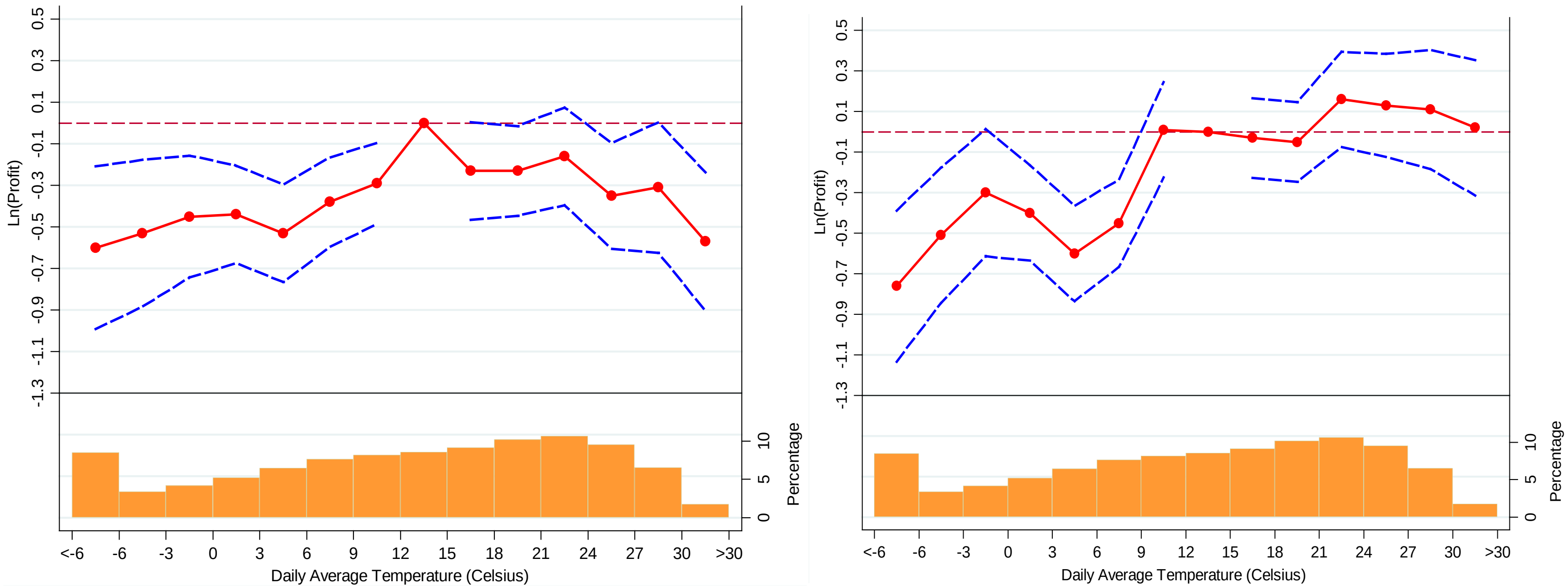
Table A3. Temperature Effects on Labor Costs, Inventory and Innovation Activity

	log(labor costs)	log(inventory)	Innovation activity (measured by ratio of new product sales to the total industrial output value)
	(1)	(2)	(3)
Number of days with T_{max} >= 35°C	0.0012*		
	(0.0006)		
L. Number of days with T_{max} >= 35°C	0.0001		
	(0.0006)		
$Temp^{spring}$		-0.0120	-0.0049***
		(0.0138)	(0.0012)
$Temp^{summer}$		0.0045	-0.0024*
		(0.0126)	(0.0014)
$Temp^{fall}$		-0.0150	0.0021*
		(0.0128)	(0.0012)
$Temp^{winter}$		0.0160	-0.0004
		(0.0110)	(0.0010)
$L.Temp^{spring}$		0.0120	-0.0029***
		(0.0139)	(0.0011)
$L.Temp^{summer}$		0.0144	-0.0031**
		(0.0135)	(0.0014)
$L.Temp^{fall}$		-0.0038	0.0042***
		(0.0115)	(0.0011)
$L.Temp^{winter}$		0.0117	-0.0009
		(0.0102)	(0.0011)
Observations	1,343,868	1,346,410	1,164,968
R^2	0.8679	0.7485	0.6432

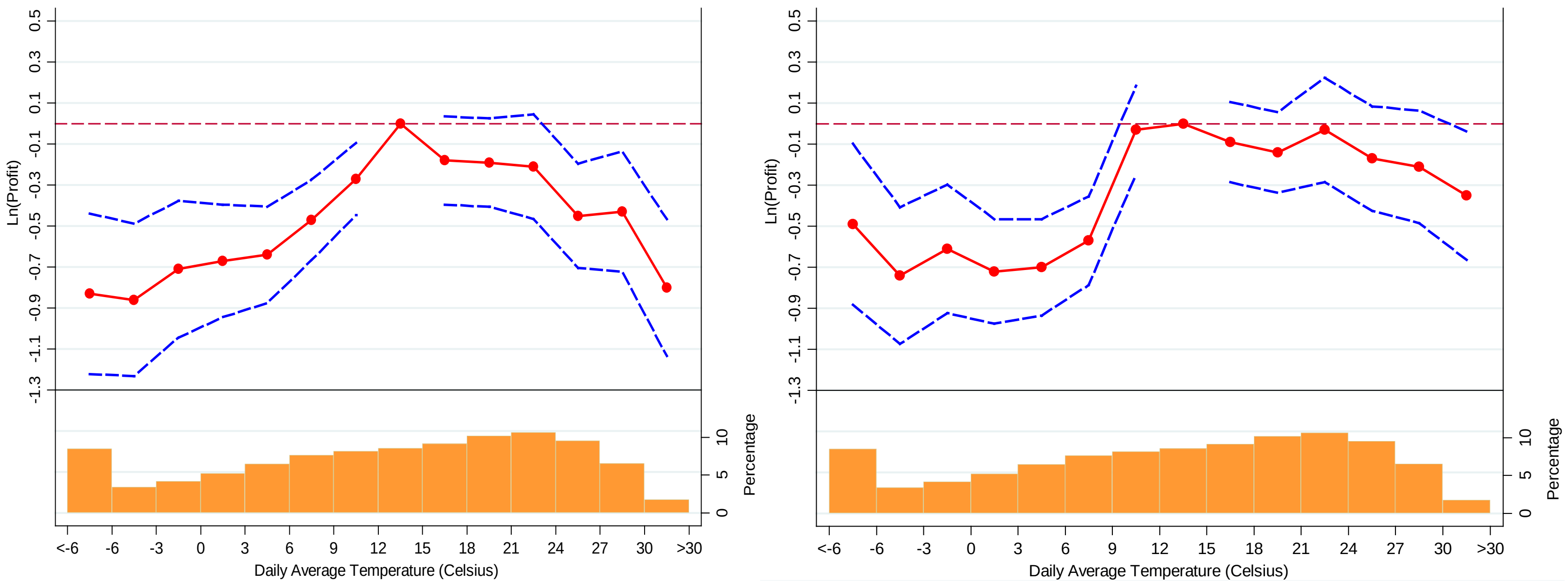
Notes: This table shows estimated temperature effects on labor costs, inventory and innovation activity, measured by the ratio of new product sales to the total industrial output value. Column (1) show the estimated temperature effect on labor costs, which is obtained by estimating Equation (4) and using the number of days with daily T_{max} above 35°C as the only temperature variable. Columns (2) and (3) show the estimated temperature effects on firms' inventory and innovation activity. These coefficient estimates are obtained by estimating Equation (4) and using seasonal average temperatures as temperature variables. All regressions include rainfall, sunshine hours, air pressure, relative humidity, and average wind speed as additional weather variables, and incorporate firm fixed effects, two-digit industry × year fixed effects, and region × year fixed effects. One lag of weather variables is incorporated as additional explanatory variables. Standard errors, shown in parentheses, are clustered within firms and within prefecture-level city-years. Units for explanatory variables: 1°C for temperature. ***p<0.01, ** p<0.05, p<0.1

Figure A1. Nonlinear Relationship between Temperature and Profit

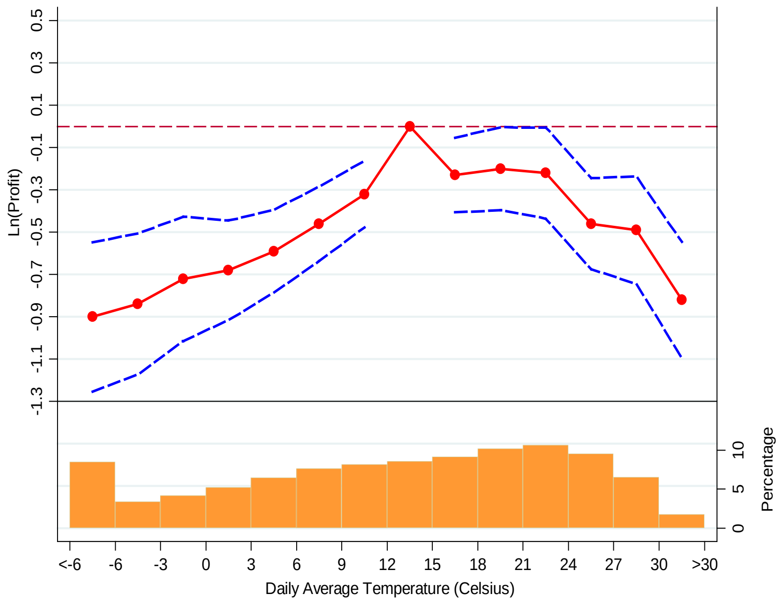
(A) Contemporaneous temperature effects (B) Lagged temperature effects

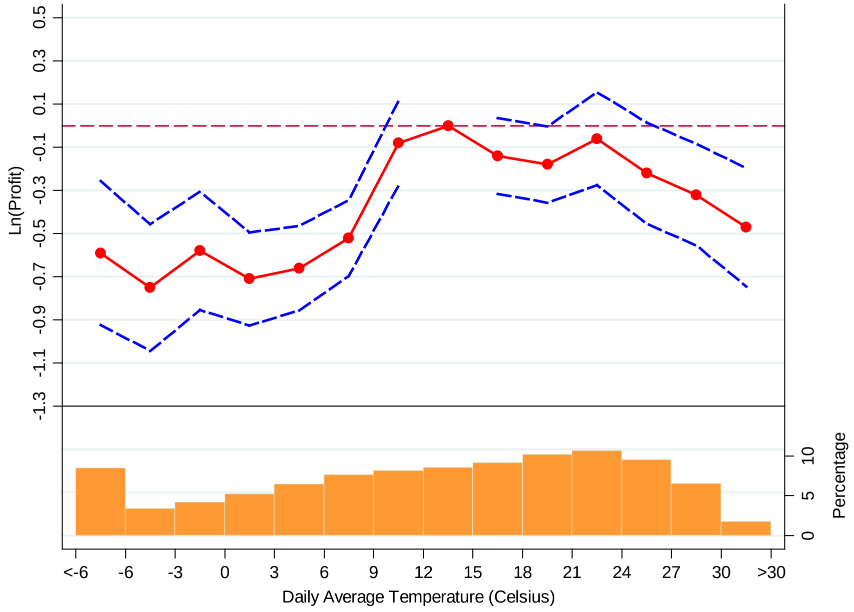


Scenario (1): Firm fixed effects and year fixed effects



Scenario (2): Firm fixed effects and region × year fixed effects





Scenario (3): Dropping observations with a stringent criterion on profit to sales ratio

Notes: These figures display the effect of daily average temperature on log profit in percentage terms. Left panels show the contemporaneous effects of daily average temperature on profit, while right panels show the lagged effects of daily average temperature on profit. The red curve in each figure represents point estimates of temperature bins, while the 95% confidence bands are added as blue dashed lines. Histograms at the bottom show the percentage distribution of each temperature bin in the sample. In Scenario (1), we consider firm fixed effects and year fixed effects only. In Scenario (2), we incorporate firm fixed effects and region × year fixed effects. In Scenario (3), we replicate the above analyses by removing observations if profit to sales ratio is either below the 0.5% level or above the 99.5% level.

Appendix B: Definitions of Chinese Regions

China is grouped into six traditional regions:

1. North: Beijing, Tianjin, Hebei, Shanxi, and Inner Mongolia;
2. Northeast: Liaoning, Jilin, and Heilongjiang;
3. East: Shanghai, Jiangsu, Zhejiang, Anhui, Fujian, Jiangxi, and Shandong;
4. South Central: Henan, Hubei, Hunan, Guangdong, Guangxi, and Hainan;
5. Southwest: Chongqing, Sichuan, Guizhou, Yunnan, and Tibet;
6. Northwest: Shaanxi, Gansu, Qinghai, Ningxia, and Xinjiang.