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Seasonal Temperature and Economic Growth in China's Major Cities

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Recent new findings reveal that the global warming has substantially negative effect on global economic growth. An important extension of this topic is to examine how localised temperature affects local economic growth. This study uses data in city's level, rather than country's level, to investigate the impact of seasonal temperature on economic growth. Temperature in city's level is more appropriate to capture and indicate the heterogeneity of local weather characteristics. We further examine these impacts on different industries. We found warmer winter helps the growth rate of economy while hotter summer harms economic growth.

Key Words: China economics; Climate change; Economic growth; Seasonal temperature.

JEL Classification Numbers: O11, O44, Q54.

1. INTRODUCTION

In the recent decades, the impact of global warming have been widely discussed by the general public[1]. In order to build up long-term stable development, China government started to publish "China's Policy's and Actions for Addressing Climate Change" each year since 2008. According to the report, the impact of climate change harms China's economy. In 2018, the direct economic loss caused by natural disaster is 264,460 million Chinese yuan. Furthermore, 133.6 million people are affected. The inten-

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[1]https://www.abc.net.au/news/2019-12-15/anger-erupts-at-un-climate-summit-as-major-economies-resist/11800786

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tion of this paper is to identify how climate change, especially temperature, affects the China's economy.

Economic development needs stable environment which secure reliable supply and government's long-term plan. However, climate change causes the economic loss, and forces the economy facing unstable environment. Since China has wide territory, it contains many different climatic types. Therefore, how to deal with its complicated climatic types across the country and how well the government understands this issue is an urgent task to China's government.

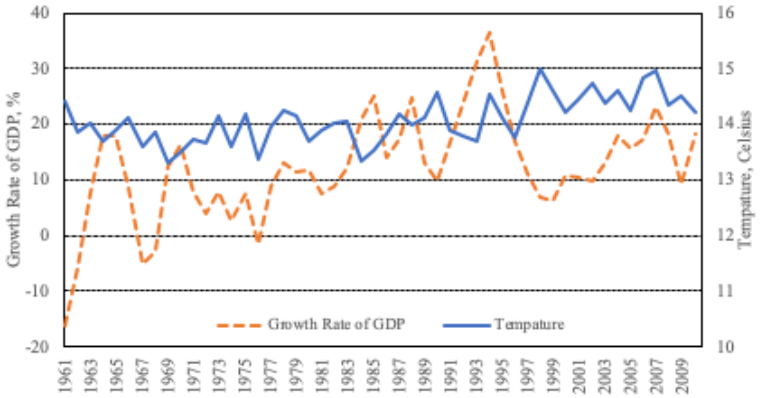
When literatures investigate the impact of global climate change, a country is generally assumed and considered as a homogeneous unit, which ignores the heterogeneous characters of different regions within a country. However, this assumption is inappropriate in the case of China as China's territory is across very wide longitude and latitude, and thus covers many different climatic types. This motivates this study to investigate the impact of climate change with the regional data in China, like one literature (Colacito, Hoffmann, & Phan, 2019) documented for the US.

Using localized data to investigate the impact of temperature on economy is much more appropriate, comparing with the use of national data. Existing literature normally uses a country's annual temperature as a controller, but this might not be the most appropriate. Annual average temperature might not be a good measurement, especially in China, because China has wide territory and many different climatic types. Under this circumstance, the impact of temperature could be mis-interpreted and thus the national average temperature cannot appropriately capture and indicate the regional heterogeneous characteristics and features. As the matter of fact, there are many levels of administrative division in China, including province, city, county, and town. Temperature is usually measured by each city to depict the general information of climate condition in China.

Figure 1 presents the growth rate of China's national gross domestic production (GDP) and its annual average temperature from 1961-2009. This data period is consistent with (M. Burke, Hsiang, & Miguel, 2015). The blue solid line indicates national average temperature in China, and the orange dash line is China's annual growth rate of GDP. Figure 1 does not show an obvious relationship between the national growth rate of economy and national annual average temperature.

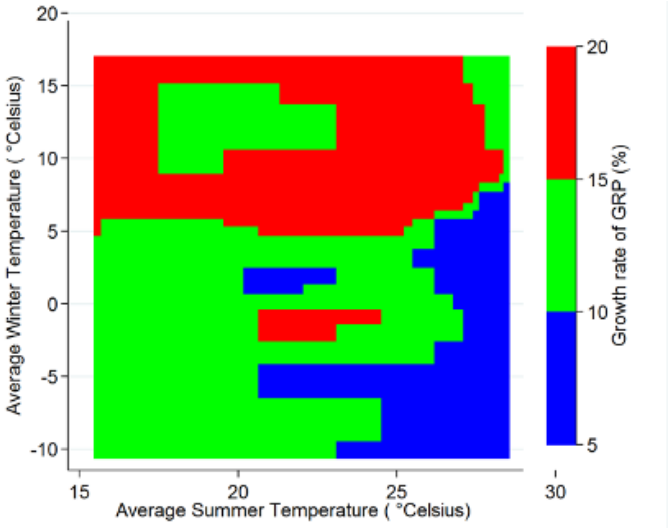
Figure 2 displays a contoured plot of the growth rate of GDP of each sample city. The colour represents the growth rate of city's GDP: 1. red denotes the city's average growth rate higher than 15% in past 10 years. 2. Green denotes the city's average growth rate is between 15% and 10% in past decade, and blue denotes those growth rates is below 5%. The x-axis is the city's average summer temperature, and the y-axis is the average winter temperature. The left-up corner indicates the cities that

FIG. 1. China's National Growth Rate of GDP and Average Temperature



have warmer winter and cooler summer, and they have relative higher growth rate of the economy. On the other hand, the right-bottom corner indicates the cities that have cold winters and hot summers, and the lower economic growth rate is observed here.

FIG. 2. Growth Rate of GDP in a City along with Average Winter and Summer Temperature



Recent studies have examined the impact of seasonal temperature on economic growth of different states in the US (Colacito et al., 2019), which shed lights of this paper to examine whether the seasonal temperature

affects the local economic growth in China. However, the information of temperature is normally measured by the level of city, rather than the level of state or province in China. Therefore, this paper uses the 31 major city's temperature with the growth rate of the economy of China in order to obtain more accurate and representative analysis.

The contributions of this study are as follows. First, this study considers the heterogeneous characters of temperature in different regions within a country and thus adopts 31 major city's temperature rather than the national average temperature. Second, there is limited study discussing issues regarding the effect of seasonal temperature in China, this study is the first to document the impact of seasonal temperature on cities' economic growth. This study also disaggregates the economy into three strata of industry in China and investigate the effect of seasonal temperature on each industry. All these contributions make this study a significant supplement to the existing literature.

The rest of this article is organized as follows: in the second section, a literature review regarding the impact of temperature on economic growth is provided followed by an introduction to the methodology in the third section. The fourth section describes the data and the fifth section discusses the empirical results. Finally, conclusions and policy implications are presented in the sixth section.

2. LITERATURE REVIEW

The impact of global warming on global economy has been widely discussed in past two decades, and its substantial negative effects on global economy has been documented (Stern, 2007). These negative effects are found even more significant in developing countries (M. B. Burke, Miguel, Satyanath, Dykema, & Lobell, 2009; Dell, Jones, & Olken, 2012; Gallup, Sachs, & Mellinger, 1999; Nordhaus, 2006). However, the statement that raises the issue regarding the temperature affects the growth rate of economic activities has been challenged in the US, especially for the sectors that are naturally exposed to outdoor weather conditions (M. Burke & Emerick, 2016; Mendelsohn & Neumann, 2004; Schlenker & Roberts, 2006, 2009). These findings emphasise that the effects of temperature on economic activities could vary due to the nature of different sectors. For example, agriculture is more relying on the weather condition, compared with manufactory industry.

Colacito et al. (2019) uses a panel regression framework with the growth rate of gross state product (GSP) and average seasonal temperatures of each state in the US to overcome existing challenges. They found that the annual temperature does not affect the growth rate of economy, but summer and autumn temperatures have an opposite effect on economic

growth. A higher average summer temperature can harms the growth rate of gross state production (GSP), while a higher autumn temperature helps this growth rate. They therefore concluded that the average annual temperature may not be an appropriate controller because it may mask its heterogenous effect on the economic growth rate due to different seasons (Colacito et al., 2019; Dell et al., 2012).

Larcom et al. (2019) shows that exposure to extreme temperatures had a substantial effect on people's perceptions of energy security, but it does not change people's behaviour to save energy. This finding suggests to policy makers that how to make effective policy to guide or to change people's behaviour becomes increasingly important.

3. METHODOLOGY

3.1. Data

This study uses the 31 major cities data from 2007 to 2017 to investigate the effect of seasonal average temperature on the economic growth. These 31 major cities are selected according to the China Statistics Yearbook: Beijing, Tianjin, Shijiazhuang, Taiyuan, Hohhot, Shenyang, Changchun, Harbin, Shanghai, Nanjing, Hangzhou, Hefei, Fuzhou, Nanchang, Jinan, Zhengzhou, Wuhan, Changsha, Guangzhou, Nanning, Haikou, Chongqing, Chengdu, Guiyang, Kunming, Lhasa, Xi'an, Lanzhou, Xining, Yinchuan, and Urumqi.

This study examines the impact of seasonal temperature on the economic growth. The growth of economy was further disaggregated into three sectors: primary industry sector, secondary industry sector, and tertiary industry sectors, and making us able to look into the impact of seasonal temperature on each of them. The definition of these three strata follows China Statistic Bureau's "Three Strata of Industry Classification of Economic Activities". All economic activities are categorized as primary industry, secondary industry, or tertiary industry according to National Economic Activities (GB/T 4754 — 2011), where the Primary industry includes agriculture, forestry, animal husbandry and fishery industries and contributed 6.3% of national GDP in 1994, but decreased to 4.1% in 2018. In addition, the secondary industry includes mining and quarrying, manufacturing, production and supply of electricity, heat, gas and water, and construction and it contributed 66% of national GDP in 1994, but reduced to 36% in 2018. Finally, the tertiary industry refers to all other economic activities not included in the primary or secondary industries and it contributed 27.4% of national GDP in 1994, and further increased to 59.7% in 2018. The wholesale and retail sectors are two major sectors in the tertiary industry sector, and they contributed 9.2% of national GDP in 2018.

All findings of this study can help policy makers to understand the different effects of climate changes on economic growth across industries and thus can make supporting policies according to the needs of different industries. For example, the electricity fee discount is more necessary due to desire in manufacturing sector than education sectors.

3.2. Econometric Models

This study uses time fixed effects model to investigate the effect of temperature on the economic growth. We first introduce Equation 1, in which the existing literature usually adopted to examine the effects of global warming on economic growth of a country. To note that this study only investigates the case of China. This setting basically regresses the country's gross domestic production (GDP) on its annual average temperature and can be expressed as follows:

$$\mathrm{GRP}_t = \alpha_0 + \beta_1 \mathrm{TEMP}_t + \beta_2 \mathrm{GRP}_{t-1} + \varepsilon_c \tag{1}$$

where the dependent variable GRP denotes to the growth rate of China's GDP. The independent variables include national annual average temperature which is presented as TEMP. This setting is suggested by M. Burke et al. (2015). However, using country level data, especially for temperature, could lead to a problematic estimation because it substantially ignores local heterogeneity. This misleading could be very serious due to the complexity of China's various climatic type.

Therefore we integrated the setting of Colacito et al. (2019) with the major cities data and average seasonal temperature. This modified setting could substantially improve Equation (1), and it is presented as Equation (2).

$$\begin{aligned} \mathrm{GRP}_{S,c,t} &= \alpha + \beta_1 \mathrm{Winter}_{c,t} + \beta_2 \mathrm{Summer}_{c,t} + \beta_3 \mathrm{PropSIS}_{c,t} \\ &+ \beta_4 \mathrm{PropTIS}_{c,t} + \beta_5 \mathrm{GRP}_{S.c.t-1} + \varepsilon_{S,c,t}, \\ &\quad \text{where } S \in \{\mathrm{AGG}, \mathrm{PIS}, \mathrm{SIS}, \mathrm{TIS}, \mathrm{NPS}\} \end{aligned} \tag{2}$$

where Winter denotes to the average winter temperature in city c in year t, and Summer denotes to the average summer temperature in city c in year t. PropSIS represents to the proportion of secondary industry sectors that contributes to aggregate production in a specified year in a city, and PropTIS is the proportion of tertiary industry sectors that contributes to aggregate productions. S as subscript of variables includes AGG, PIS, SIS, TIS, NPS, where AGG denotes to the aggregate industry sectors. PIS denotes to the primacy industry sectors, SIS represents the secondary industry sectors, and TIS represents the tertiary industry sectors. NPS denotes to the non-primary industry sectors, which is the summation of secondary and tertiary industry sectors.

This formula not only investigates the effect of seasonal temperature on aggregate economy, but also on different industry sectors. We disaggregate the general domestic production according to the different industries. Therefore, this study uses five models to investigate the effect of seasonal temperature. This disaggregation helps to understand whether the effects of seasonal temperature varies by industries.

3.3. Variables

Table 1 provides the descriptive statistics. The average annual temperature in China is 14.07 degree of Celsius. The lowest annual average temperature is 13.29 degree, and the highest annual average temperature is 15. The average winter temperature is 4.4 degree while the lowest winter temperatures is −15 degree in Harbin in 2013 and warmest winter temperature is 21.07 degree in Haikou in 2013.

The average aggregate growth rate of GDP in cities' level is 12.63%. The lowest aggregate growth rate of city's GDP is −25% (Shenyang in 2016) and the highest growth rate of city's GDP is 34.61% (Hefei in 2011). The average growth rate of primary industry sector in cities' level is 8.36%. The lowest growth rate of primary industry sectors is −23.28% (Tianjin in 2017) and the highest growth rate is 56.9% (Hefei in 2011). The average growth rate of cities' secondary industry sector is 10.71%. The lowest growth rate of secondary industry sectors is −38.53% (Shenyang in 2016) and the highest growth rate is 37.46% (Hefei in 2011). The average growth rate of cities' tertiary industry sector is 14.73%. The lowest growth rate of tertiary industry sectors is −13.58% (Hohhot in 2017) and the highest growth rate is 37.57% (Guiyang in 2009). The average growth rate of cities' non-primary industry sector is 12.91%. The lowest growth rate of non-primary industry sectors is −25.06% (Shenyang in 2016) and the highest growth rate is 33.56% (Yinchaun in 2010).

This wide ranges of cities' annual, winter, and summer temperature demonstrate the heterogeneous characteristics of major cities in China, which also implies that using only country's temperature is not appropriate to capture the diversity of each city.

4. RESULTS

Table 2 presents the results of time fixed effect model on the growth rate of gross domestic product in 31 major cities. Column 1 shows how the country's annual temperature affects country's economy. There is no evidence that country's annual temperature harms country's economy.

Column 2 presents the results which achieved by using both average winter and summer temperature as controllers to investigate whether seasonal temperature affects a city's economic growth. Spring and autumn tem-

TABLE 1.

Descriptive of Variables

	Mean	Standard Deviation	Min	Max
GRP (nation)	12.91	8.51	−5.69	36.34
TEMP (nation)	14.07	0.416	13.29	15
Observations	49			
GRP_{AGG}	12.63	6.493	−24.92	34.61
GRP_{PIS}	7.587	8.922	−23.28	56.9
GRP_{NPS}	12.88	6.59	−25.06	33.56
GRP_{SIS}	10.62	9.489	−38.53	37.46
GRP_{TIS}	14.74	6.048	−13.58	37.57
Winter	4.394	7.537	−14.97	21.07
Summer	24.32	3.635	14.77	29.7
PropSIS	0.426	0.0894	0.181	0.587
PropTIS	0.528	0.0967	0.362	0.806
Observations	273			

peratures are not included in the regression because spring temperature is highly correlated with summer temperature, whilst autumn temperature is highly correlated with winter temperature. Column 2 shows that a higher winter temperature can be helpful to a city's economy: 1-degree warmer causes 0.193% increasing of city's growth rate. Meanwhile a hotter summer can harm a city's economy. An one degree hotter in summer will cause a decrease in a city's growth rate by 0.204 percentage point. Empirical results in columns $3 \sim 6$ show how the winter and summer temperatures affect the economy of the primary industrial sector, the non-agriculture sector, the secondary industrial sector, and the tertiary industrial sector, respectively.

In the estimations of primary industry sector (Column 3), an increase in average summer temperature will decrease the growth rate of the primary industry sector of local economy, while the average winter temperature has a statistically significant and positive effect on the growth rate of primary industry economy of local economy. This is understandable because a higher average summer temperature could be too hot for crop to grow. A hot temperature is also difficult to keep livestock well, further makes people have to increase the cost of cooling facilities. A warmer winter is beneficial to the primary-industry economy because farmers could save the cost of heating during the winter. A warmer winter thus has substantial positive effect on the economic growth rate of primary industry economy of local economy. The positive effect of a warmer winter on the economic growth is

about twice larger than the harms resulting from a hotter summer in the primary industry.

We also found that the magnitude of the positive effects of the winter temperature and that of the negative effect of the summer temperature are at a similar level in the non-primary industry. Both of them have a significant effect on on the economic growth of non-primary sector, motivating us to further investigate via disaggregate the non-primary industry into the secondary industry and the tertiary industry.

TABLE 2.

Results of Time fixed effect models.

	Nation	Aggregate	Primary Industry	Non-Primary Industry	Secondary Industry	Tertiary Industry
TEMP	0.232					
	(2.506)					
Winter		0.193^{***}	0.217^{***}	0.203^{***}	0.268^{***}	0.207^{***}
	(0.053)	(0.073)	(0.054)	(0.081)	(0.056)	
Summer		-0.204^{**}	-0.414^{***}	-0.209^{**}	-0.325^{**}	-0.190^{*}
	(0.091)	(0.150)	(0.092)	(0.156)	(0.107)	
PropSIS		11.10	−8.524	7.912	4.273	17.71^{**}
		(6.867)	(14.029)	(7.177)	(10.906)	(8.756)
PropTIS		4.141	−21.08	0.651	−12.04	9.196
		(6.360)	(13.002)	(6.646)	(10.620)	(8.017)
GRP_{t-1}	0.622^{***}					
	(0.092)					
$GRP_{AGG,t-1}$		0.315^{***}				
		(0.081)				
$GRP_{PIS,t-1}$			0.0399			
			(0.058)			
$GRP_{NPS,t-1}$				0.304^{***}		
				(0.079)		
$GRP_{SIS,t-1}$					0.227^{***}	
					(0.067)	
$GRP_{TIS,t-1}$						0.111
						(0.071)
Constant	2.052	4.353	29.57^{**}	8.296	16.14	7.030
	(35.640)	(6.830)	(12.874)	(7.158)	(11.093)	(8.411)
Time FE		X	X	X	X	X
Observations	49	273	273	273	273	273
R^2	0.478	0.585	0.331	0.576	0.617	0.285

Note: Data in Column 1 is from (M. Burke et al., 2015), which uses the country level of dataset. Data in Column 2-6 is from China Statistics Bureau, which uses dataset based on city's level. standard error is in the parenthesis. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

The results of secondary industry (Column 5) suggest that a warmer winter has a positive effect on the economic growth of secondary industry, while a hotter summer had a negative effect on it. This is because an increase in the winter temperature can make manufacturers save the cost of keeping the working environment more friendly/suitable to both workers and machines and further benefits the economy. The positive effect of a warm winter is slightly smaller than the harm resulting from a hot summer in the secondary industry. This is because an increase in the summer temperature can make workers' working environment more difficult and uncomfortable, which reduce their working efficiency and motivation, and further damage the economy.

The growth rate of tertiary industry sector is affected by seasonal temperature as well (Column 6). The empirical results show that the winter temperature has a statistically significant and positive effect on the economic growth rate of tertiary industry sector, while this beneficial effect is greater than the loss caused by a hotter summer. This implies that the seasonal temperature has consistent effects on all industries, but the magnitude of effects in winter and summer are quite different.

5. CONCLUDING REMARKS

This study attempts to examine how localised temperature affects local economic growth. Using the city-level panel data of 31 major cities from 2007 to 2017 and dividing economy into three sectors, primary, secondary, and tertiary, five fixed-effect models are estimated. The primary finding of this study is that the effect of annual temperatures on economic growth is neutralised because the effects of average winter and summer temperature on the aggregate economic growth have an opposed sign. This conclusion is consistent with that in the US (Colacito et al., 2019), indicating that seasonal temperatures have heterogeneous effects on the aggregate economy.

This study further finds that a hotter summer will harm the economic growth of all industrial sectors, while a warmer winter will be helpful. Interestingly, the magnitude of seasonal temperature effect is different by industrial sectors. It could be the advantage of information technology (IT) which prevents most tertiary industry sectors from impact of temperature change. For example, when the heat wave arrives, workers are struggling in the over-heating environment, which classified as secondary industry, but people could stay at home to complete their on-line trading, which is classified as tertiary industry. However, the persuasive reasons why the different effects occur need further investigations.

To pursue a higher economic growth rate is always a very important goal for the Government of China (GoC). According to the finding of this study, the magnitude of the positive effects of the winter temperature on

the economic growth rate is less than that of the negative effect of the summer temperature in the entire economy, the primary sector, and the secondary sector, implying that a one degree Celsius increases in temperature of both summer and winter will cause a decrease in China's economic growth rate. That is to say, global climate warming will harm China's economy. Therefore, this study suggests the GoC should pay more attention to issues regarding global climate warming, especially its impact on China's economy. The GoC should consider implementing more effective measures and regulations to reduce the level of carbon dioxide, chlorofluorocarbons (CFCs), and other pollutants in China as they are treated as the causes of global warming. Doing so will benefit not only China's economy but also the global environment.

The limitation of this study is the data only based on major cities level, which means the rural areas and regions could not be assessed. Additionally, the proportion of gross domestic production contributed by primary industry sector in a city is less than 5 percent of aggregate gross domestic production in major cities. It could be more meaningful to represent the primary industry sector by using the data of the rural province, areas, or towns. If future study could include more localised rural areas, it could substantially strengthen the interpretation of the findings. However, we couldn't explore it further due to limit access of local data. We would like to leave it as a study in the future.

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