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Article

Climate change and economic sectors in developed and developing countries

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Abstract: Climate change is the most important environmental problem of the 21st century. Severe climate changes are caused by changes in the average temperature and rainfall can affect economic sectors. On the other hand, the impact of climate change on countries varies depending on their level of development. Therefore, the aim of this paper is to investigate the relationship between climate changes and economic sectors in developed and developing countries for the period 1990–2021. For this purpose, a novel approach based on wavelet analysis and SUR model has been used. In this case, first all variables are decomposed into different frequencies (short, medium and long terms) using wavelet decomposition and then a SUR model is applied for the examination of climate change effects on agriculture, industry and services sectors in developed and developing countries. The findings indicate that temperature and rainfall have a significant negative and positive relationship with the agriculture, industry and services sectors in developed and developing countries, respectively. But severity of the negative effects is greater in the agricultural and industrial sectors in all frequencies (short, medium and long terms) compared to service sector. Furthermore, the severity of the positive effects is greater in the agricultural sector in all frequencies of developing countries compared to the industrial and services sectors. Finally, developing countries are more vulnerable to climate change in all sectors compared to developed countries.

Keywords: climate change; economic sectors; wavelet analysis; Seemingly Unrelated Regressions (SUR)

1. Introduction

The most countries are facing unprecedented challenges due to the severe global warming. Temperatures and the frequency of extreme rainfall events have increased dramatically over the past 40 years. The average temperature in developing countries is expected to increase and the amount of precipitation will be decreased by the end of this century. Therefore, economic losses due to climate damages in developing countries could be more severe than the global average level and these changes will decrease GDP (Duan et al., 2022).

The negative effects of climate change on economic sectors have been highlighted by the Intergovernmental Panel on Climate Change. The panel asserted that global average losses for 4 degrees of warming could be 1%–5% of GDP (IPCC, 2007). Global warming not only affects production levels, but also reduce the economic growth (Dell et al., 2012). Furthermore, it could increase the heat-related deaths in more populous cities (Banerjee and Maharaj, 2020).

Climate change may also introduce large shocks to the energy system and global electricity demand may grow by an average of 2.8% in 2100 (Auffhammer et al., 2017). In addition, investment, trade and political stability are also among the main challenges of global warming, which negatively affects the social economy. In less developed countries, each additional increase in temperature harms the national income by 8.5 percent (Dell et al., 2008). There is little discussion about the adverse impact of climate change on a global scale, and due to relatively limited research and a lack of empirical evidence, there is still much uncertainty about the possible effects of global warming in different regions and sectors.

The aim of this research is to examine the relationship between climate change and economics sectors including agriculture, industry and services in developed and developing countries. Therefore, this study puts forward the following hypotheses:

Hypothesis 1. Climate change (proxied by temperature and rainfall) has a significant impact on economic sectors in developed and developing countries in different frequencies.

Hypothesis 2. Developing countries are more vulnerable to climate change in all sectors compared to developed countries.

The selection of an appropriate proxy for climate change is a difficult issue. The rationale behind the selection of temperature and precipitation is based on the following reasons. First, Climate is determined by the long-term pattern of temperature and precipitation averages. Second, precipitation can affect the amount of water available for drinking, irrigation, and industry. Finally, there is direct relationship between greenhouse gas concentration and changes in mean temperature.

2. Literature review

Many studies have paid attention to the impacts of climate change on economic activities. Akram (2012) analyzed the impacts of climate change on economic growth for Asian countries and came to the conclusion that there is an inverse relationship between economic growth and changes in temperature and precipitation. Alagidideh et al. (2016) investigated the impact of climate change on the sustainable growth of sub-Saharan Africa and found that temperatures beyond 24.9 °C would significantly reduce economic growth. Wade and Jennings (2016) examined the effects of climate change on the global economy using climate loss functions. According to the findings, the increase in global temperature was accompanied by an increase in operating costs, which will harm the global economy and cause a one percent decrease in GDP growth. So that this impact was greater for developing countries and the long-term financial consequences of climate change can only be reduced by imposing more restrictions on carbon emissions. Du et al. (2017) studied the impact of climate changes on the economic growth of the United States and European Union. The findings indicate that the long run increase in temperature has a negative effect on the economic growth of these countries. These studies are more important from the point of view of the consequences of climate change, in terms of the quantitative method used. In this study, besides the fact that the phenomenon of climate change was considered through the temperature variable, other factors determining economic growth were also included in the model. Ogbuabor and Egwuchukwu (2017) considered the impact of climate change on the growth of the Nigerian economy and indicated that carbon emissions have a negative effect on long-term and short-term economic growth. Berlemann and Wenzel (2018) examined the effects of hurricanes on economic growth and found that the negative long-run effects of tropical storms depend on the level of development of the countries, the low-income countries are more damaged by the disasters. Kahn et al. (2019) investigated the long-term macroeconomic effects of climate change in 174 countries for the period 1960–2014 and showed that economic growth is negatively affected by permanent changes in temperature and precipitation does not have any statistically significant effect. Henseler and Schumacher (2019) studied the effect of weather on economic growth in 103 countries for the period 1961–2010. Their findings shows that the poor countries are much more damaged by higher temperature than rich countries and also the weather affects the GDP growth mainly through total factor productivity. Letta and Tol (2019) directly examined the relationship between temperature shocks and TFP growth rates for the period 1960–2006 using macro TFP data. Because total factor productivity (TFP) and physical and human capital accumulation are important for long-term economic growth, they stated that an increase of only 1 °C in annual temperature values would reduce the TFP growth rate by 1.1%–1.8%. Lee et al. (2020) investigated the effect of temperature shocks on economic growth and welfare in Asia in the period of 1960–2014 using the profit and loss function. For this purpose, they predicted temperature changes until 2030 and 2100 and investigated the effect of temperature changes on agriculture, industry, services and investment sectors. The findings indicated that with the increase in temperature, the economic productivity in Asian countries will be at least 10% lower than usual by the year 2100. Duan et al. (2022) considered the effect of climate change on China's economic growth during the period 1990-2016. The findings indicated that with an increase in temperature by 1 degree Celsius the GDP growth will be decreased by 0.78% while with the increase of 100 mm-rainfall, the GDP growth will be increased by 0.86%. Khurshid et al. (2022) investigated the effect of climate shocks on the economic growth of Pakistan with linear and non-linear ARDL model during the period 1980–2021. The findings indicated that CO_2 emissions and average temperature create asymmetric effects on economic growth in the long and short term. CO_2 emission and temperature increase have a negative effect on economic growth while precipitation has a positive and significant effect on economic growth in the long term. Farajzadeh et al. (2022) examined the consequences of climate shocks on economic growth in Iran and found that the climate change has a significant effect on economic growth. The effects of capital damage from climate change are more significant and the fall in consumption and welfare is far higher than the corresponding output reduction. Benhamed et al. (2023) examined the relationship between climate change and economic growth. Their results indicate direct and indirect spillover effects of climate change on economic growth in countries with low average income in the short and long term. Disaggregation by climate regime also yields interesting findings because climate change has adverse direct and indirect spillover effects on economic growth only in the warmest countries in the long run. Petrović (2023), using a plug-in model averaging approach, concluded that the impact of climate change on economic growth is very heterogeneous across countries and the average effect is still positive. Tao et al. (2023) studied the impact of climate change and technological innovation on economic growth in Asian and European countries for the period 1996–2021. They revealed that the impact of technological innovation on economic growth has significant regional heterogeneity so that the technological innovation has stimulated the economic growth only in European countries. They also found that the technological transfer from European countries has resulted in abnormal climate change in Asian countries. Finally, Desbordes and Eberhardt (2024) showed that, in low-income countries, a permanent 1 °C increase in temperature reduces income per capita of about 1.3% in the short-run and 8.5% in the long run.

As indicated in this section, much research has been devoted to the effect of climate change on economic growth. However, most of the studies have focused on individual countries or panel data of counties in Asia, Africa or Europe. There is a lack of study on the relationship between climate change and economic sectors including agriculture, industry and services from the level of development point of view and from time-frequency perspective. This research attempts to fill in this gap by a novel approach, a wavelet-based SUR model which can examine the relationship between climate change and economic sectors in developed and developing countries in different frequencies (short term, medium term and long term).

3. Methodology

In this research, the SUR model and wavelet analysis are used to investigate the effect of climate change on economic sectors in developed and developing countries. Wavelet analysis provides a deeper insight and broader discussion about the relationship between climate change and economic growth. The wavelet model is an extension of spectral analysis (Mandler and Shrangel, 2014). Wavelet analysis can reveal the frequency components of variables just like Fourier transform, in addition to extracting time series features. It is a sophisticated time-frequency analysis technique that is superior to pure time series or frequency domain methods. As a result, it is widely used for data processing and econometric analysis. While the Fourier transform decomposes a time series into constituent sinusoids of different frequencies and infinite duration, the wavelet transform expands the time series into modified and scaled versions of a function, the so-called mother wavelet, which has a limited spectral band (Aguiar-Conraria et al., 2018).

Discrete wavelet transform (DWT) and continuous wavelet transform (CWT) are two classes of wavelet transform. DWT is useful for noise reduction and data compression while CWT is more useful for extracting features and detecting the similarity of the data itself (Grinsted et al., 2004).

In application, continuous wavelet transform is often chosen to extract information from economic variables and perform correlation and causality analysis. In fact, wavelets are highly useful mathematical tools in analyzing the data in two time and frequency domains within a unified framework. In this way, wavelets enable researchers to explore simultaneously how variables are related at different frequencies and how such relationship has evolved over time (Rua, 2012). Therefore, the wavelet approach suffers less estimation bias than empirical methods developed to identify purely economic relationships in the time domain.

The wavelet is used when the series is non-stationary and it is also used in infinite sets. Wavelet analysis shows the spectral characteristics of a time series. Discrete wavelet is used in this study. The maximal overlap discrete wavelet transform (MODWT), as one of the types of discrete wavelet, is a linear filtering operation that decomposes the original time series into different time scales and has the ability to check series with any length (all sample sizes).

A time series $x(t)$ can be represented as a linear combination of wavelet functions (Saldivia et al., 2020):

$$X_t = \sum_k s_{j,k}\phi_{j,k}(t) + \sum_j d_{j,k}\psi_{j-1,k}(t),\ j=1,\ldots,J \quad (1)$$

J is the decomposition level, k is the transfer parameter, $\phi_{j,k}(t)$ and $\psi_{j-1,k}(t)$ are father and mother wavelets and $s_{j,k}$ and $d_{j,k}$ are scaling and the details coefficients respectively. These coefficients are obtained by projecting $X(t)$ in the wavelet function.

$$s_{j,k} = \int X_t\phi_{J,k}(t)dt \quad (2)$$

$$d_{j,k} = \int X_t\psi_{J,k}(t)dt,\ \ j=1,\ldots,J \quad (3)$$

The father wavelet characterizes the smooth and low-frequency parts of a signal (the raw data) and contains information related to the general movement of the wavelet function while the mother wavelet represents the detailed and the high frequency parts of a signal and contains information related to the details of the function.

By choosing the mother wavelet, the wavelet transform can be used to analyze the signal according to the time scale. There is an inverse relationship between the behavior of the signal and the time scale, so that the low time scale corresponds to the compressed wavelet in which the details change quickly, that is, they have a high frequency while the upper time scale is related to the elongated wave and has a low frequency. The representation of $X(t)$ signal is expressed as follows:

$$X_t = S_J(t) + D_J(t) + D_{J-1}(t)+\ldots+D_1(t) \quad (4)$$

Multivariate analysis is the achievement of successive approximations of a series, D_{J-1}, D_{J-2}, D_J and such that each approximation is a better representation of the original series. $D_{J-i}(t)$ represents the crystal regeneration associated with a certain time scale, while $S_J(t)$ is the residual series of the process. In this study, the mother wavelet of the decomposition level is set at $J = 4$. The following relationship shows the wavelet analysis process:

$$j=4 \rightarrow X=D_1 + D_2 + D_3 + D_4 + S_4 \quad (5)$$

Considering the annual series, component D1 records the movements of the series in the short term (2–4 years), D2 in the medium term (4–8 years), D3 in the long term (8–16 years) and D4 the behavior of the series in more than 16 years. Based on literature, the econometric model is specified as follows:

$$y_{it} = \alpha_0 + \alpha_1 hc_{it} + \alpha_2 pop_{it} + \alpha_3 ur_{it} + \alpha_4 tmp_{it} + \alpha_5 pr_{it} + \varepsilon_{it} \quad (6)$$

where y represents the growth rate of GDP and hc, pop, ur, tmp, pr are human capital, population growth, urbanization, temperature and precipitation respectively.

To see which part of the economy is most affected by climate changes, the seemingly unrelated regressions (SUR) will be used based on economic sectors of GDP, i.e., agriculture (Ag), manufacturing (Mn) and services (Sr):

$$Ag_{it} = \alpha_0 + \alpha_1 hc_{it} + \alpha_2 pop_{it} + \alpha_3 tmp_{it} + \alpha_4 pr_{it} + \xi_{it} \quad (7)$$

$$Mn_{it} = \alpha_0 + \alpha_1 hc_{it} + \alpha_2 pop_{it} + \alpha_3 tmp_{it} + \alpha_4 pr_{it} + \psi_{it} \quad (8)$$

$$Sr_{it} = \alpha_0 + \alpha_1 hc_{it} + \alpha_2 pop_{it} + \alpha_3 tmp_{it} + \alpha_4 pr_{it} + \delta_{it} \quad (9)$$

The SUR model is a method for analyzing systems with multiple related regression equations. This model contains only exogenous regressors and the equations are only related through the error terms. The aim is to estimate the model in different frequencies (short term, medium term and long term).

The required data including population growth rate, human capital (secondary school enrollment), urbanization (percentage of urban population compared to the total population), temperature (average annual temperature based on monthly data), rainfall (average annual rainfall based on monthly data) and the added value of agriculture, industry and services in selected developed and developing countries are obtained from the World Bank for the period 1990–2021 (World Bank, 2021). All variables are decomposed into different frequencies D1, D2, D3 and D4 using wavelet package in R.

Developed countries include Australia, Austria, Belgium, Canada, Denmark, Finland, France, Germany, Iceland, Italy, Japan, Netherlands, New Zealand, Norway, Singapore, Spain, Sweden, Switzerland, United Kingdom, United States, South Korea and developing countries consist of Brazil, Bulgaria, Colombia, Costa Rica, Egypt, Iran, Iraq, Kazakhstan, Mexico, Pakistan, Panama, Peru, Philippines, Romania, Sri Lanka, Thailand, Argentina, Chile, Hungary, Poland, Russian Federation and Turkey.

4. Empirical results

Table 1 presents the descriptive statistics of the data used to investigate the effect of temperature and rainfall on economic growth in developed countries. During the period 2000–2021, the average economic growth of developed countries is 2.46%. The average population growth in this group of countries is 0.72%, the average secondary enrollment rate is 114.06%, the urbanization rate is 18.4%, the average temperature is 25.54 degrees Celsius and the average rainfall is 1082.6 mm.

Table 1. Descriptive statistics of the data (developed countries, 2000–2021).

Variable	Average	Standard Deviation	Minimum	Maximum
Economic Growth (%)	2.46	3.2	−15.3	13.04
Population growth (%)	0.72	0.7	−4.17	5.32
Urbanization rate (%)	18.4	9.94	2.3	42.8
Human capital (secondary school enrollment rate)	114.06	17.9	78.6	163.9
Temperature (Celsius)	25.54	9.06	−2.43	40.1
Rainfall (mm)	1082.6	516.8	534	2497
added value of the agricultural sector (billion dollars)	1680	63500	0.1	33400
added value of the industry sector (billion dollars)	29500	108000	41.8	651000
added value of the services sector (billion dollars)	53900	182000	88.3	1080000

Source: Research findings.

Table 2 shows the descriptive statistics of developing countries. The average economic growth of developing countries is 3.67 percent and is more than that of developed countries. Furthermore, the temperature and rainfall averages of developing countries, 26.7 Celsius and 1173.4 mm respectively, are higher as compared to developed countries.

Table 2. Descriptive statistics of the data (developing countries, 2000–2021).

Variable	Average	Standard Deviation	Minimum	Maximum
Economic Growth (%)	3.67	5.26	−36.6	53.3
Population growth (%)	0.98	0.97	−2.17	4.66
Urbanization rate (%)	35.7	17.8	7.7	81.8
Human capital (secondary school enrollment rate)	88.12	19.4	22.5	142.01
Temperature (Celsius)	26.7	7.5	−0.75	43.1
Rainfall(mm)	1173.4	956.3	18.1	3240
added value of the agricultural sector (billion dollars)	56500	249000	0.78	1600000
added value of the industry sector (billion dollars)	22000	930000	2.64	5220000
added value of the services sector (billion dollars)	325000	1380000	9.98	8390000

Source: Research findings.

The next part includes the estimation results of the models. To do so, first, the stationarity of the variables are examined. Then, the results of estimated model of economic sectors using seemingly unrelated regression (SUR) are presented. The results of the unit root test, using Levin, Lee and Chu test statistics and ADF-Fisher test, in developed and developing countries has been investigated. The results reported in **Tables 3–6** indicate that all variables are stationary at level or their first order differences.

Table 3. Stationary test of variables at the level (developed countries).

	Levin- Lee and Chu test			ADF-Fisher test		
Variable	**intercept**	**intercept and trend**	**non**	**intercept**	**intercept and trend**	**non**
Population growth	−3.1 (0.0009)	−2.84 (0.0022)	−3.8 (0.0001)	76.9 (0.0015)	77.6 (0.0013)	67.9 (0.014)
Urbanization rate	−21.6 (0.000)	−7.9 (0.000)	−8.4 (0.000)	352.7 (0.000)	84.25 (0.0001)	153.4 (0.000)
Human capital	2.33 (0.99)	1.84 (0.96)	1.09 (0.86)	36.8 (0.76)	30.07 (0.94)	21.18 (0.99)
temperature	50.97 (000/1)	72.87 (000/1)	1.59 (0.94)	121.8 (0.000)	165.8 (0.000)	20.8 (0.99)
rainfall	−4.4 (0.000)	−8.7 (0.000)	−3.3 (0.05)	−4.5 (0.001)	−7.4 (0.000)	−3.8 (0.06)
added value of the agricultural sector	−0.65 (0.25)	0.46 (0.67)	4.08 (000/1)	60.6 (0.04)	82.6 (0.0004)	14.8 (0.001)
added value of the industry sector	−15.1 (0.12)	3.19 (0.99)	4.78 (000/1)	26.7 (0.98)	41.27 (0.58)	7.66 (0.001)
added value of the service sector	−0.64 (0.25)	−0.39 (0.34)	18.9 (000/1)	21.9 (0.99)	76.7 (0.0016)	0.86 (0.001)

Source: Research findings.

Table 4. Stationary test of variables with first order differences (developed countries).

	Levin-Lee and Chu test			ADF-Fisher test		
Variable	**intercept**	**intercept and trend**	**non**	**intercept**	**intercept and trend**	**non**
Population growth	-	-	-	-	-	-
Urbanization rate	-	-	-	-	-	-
Human capital	−32.2 (0.01)	−2.3 (0.07)	−12.2 (0.000)	125.5 (0.000)	83.7 (0.0003)	210.2 (0.000)
temperature	−53.88 (0.000)	−13.8 (0.000)	−68.3 (0.000)	-	-	501 (0.000)
rainfall	-	-	-	-	-	-
added value of the agricultural sector	−23.8 (0.000)	−43.4 (0.000)	−17.2 (0.000)	-	-	340.3 (0.000)
added value of the industry sector	−2.06 (0.01)	−4.84 (0.000)	−11.7 (0.000)	167.6 (0.000)	122.8 (0.000)	216.1 (0.000)
added value of the service sector	−10.6 (0.000)	−89.3 (0.000)	73.6 (0.000)	290.8 (0.000)	-	170.03 (0.000)

Source: Research findings.

Table 5. Stationary test of variables at the level (developing countries).

	Levin-Lee and Chu test			ADF-Fisher test		
Variable	**intercept**	**intercept and trend**	**non**	**intercept**	**intercept and trend**	**non**
Population growth	−38.2 (0.06)	−3.47 (0.05)	−2.69 (0.003)	102.7 (0.000)	70.4 (0.006)	62.7 (0.03)
Urbanization rate	−26.5 (0.000)	−59.4 (0.000)	75.2 (0.003)	132.1 (0.000)	66.6 (0.01)	179.8 (0.000)
Human capital	−1.2 (0.11)	−2.05 (0.02)	4.34 (0.99)	25.3 (0.98)	54.4 (0.13)	66.6 (0.99)
temperature	29.9 (0.99)	39.4 (0.99)	15.1 (0.87)	35.2 (0.82)	39.6 (0.66)	14.4 (0.99)
rainfall	−1.97 (0.02)	−1.4 (0.07)	−2.33 (0.009)	5.76 (0.05)	15.5 (0.0004)	6.39 (0.04)
added value of the agricultural sector	8.4 (0.99)	0.48 (0.68)	48.8 (0.99)	36.8 (0.77)	47.09 (0.34)	5.24 (0.99)
added value of the industry sector	−2.72 (0.003)	15.5 (0.99)	3.18 (0.99)	26.4 (0.94)	24.3 (0.99)	6.1 (0.99)
added value of the service sector	2.1 (0.98)	2.5 (0.99)	12.7 (0.99)	15.3 (0.99)	39.7 (0.65)	39.3 (0.99)

Source: Research findings.

Table 6. Stationary test of variables with first order differences (developing countries).

	Levin-Lee and Chu test			ADF-Fisher test		
Variable	**intercept**	**intercept and trend**	**non**	**intercept**	**intercept and trend**	**non**
Population growth	-	-	-	-	-	-
Urbanization rate	-	-	-	-	-	-
Human capital	−7.01 (0.000)	−5.52 (0.000)	−11.1 (0.000)	159.6 (0.000)	123.8 (0.000)	217.3 (0.000)
temperature	−54.7 (0.000)	−28.4 (0.000)	−61.5 (0.000)	353.5 (0.000)	267.1 (0.000)	437.5 (0.000)
rainfall	-	-	-	-	-	-

Table 6. (*Continued*).

	Levin-Lee and Chu test			ADF-Fisher test		
Variable	**intercept**	**intercept and trend**	**non**	**intercept**	**intercept and trend**	**non**
added value of the agricultural sector	−14.3 (0.000)	−11.8 (0.000)	−27.2 (0.01)	200.2 (0.000)	160.3 (0.000)	206 (0.000)
added value of the industry sector	−3.16 (0.000)	−2.64 (0.004)	−6.62 (0.000)	141.5 (0.000)	141.9 (0.000)	102.7 (0.000)
added value of the service sector	−4.8 (0.000)	−5.2 (0.000)	−6.5 (0.000)	248.8 (0.000)	195.3 (0.000)	122.01 (0.000)

Source: Research findings.

Since some variables are I (1), and in order to avoid spurious regression results, it is necessary to check for the presence of cointegrating relationship. For this purpose, Kao cointegration test has been conducted, and the results are reported in **Table 7**. According to the results and rejecting the null hypothesis, there is a long run relationship between the variables in developed and developing countries.

Table 7. Kao cointegration test.

	value	**Prob.**
Developed countries	−12.94	0.000
Developing countries	−8.65	0.012

To estimate the hybrid model, first all variables are decomposed into different frequencies, D1 (2–4 years), D2 (4–8 years), D3 (8–16 years) and D4 (more than 16 years), using wavelet decomposition and then for each of the four data sets (D1, D2, D3 and D4), the different SUR models can be estimated for the examination of climate change effects on agriculture, industry and services sectors in developed and developing countries.

The results of the estimated seemingly unrelated regression (SUR) for developed countries in different frequencies (D1, D2, D3, and D4) are shown in **Table 8**. The results show that human capital has a positive relationship with all sectors of GDP in medium and long terms while other variables such as population growth and temperature have a negative and significant effect in all sectors and frequencies. These results are in line with the literature. Sultana et al (2022) found that human capital positively influences economic growth in developed and developing countries but the effect of human capital on economic growth is not the same for all levels of development. The negative effect of population growth on economic growth confirms Malthus' theory. Dell et al. (2012) concluded that economic prosperity in low-income countries is much more suffered by temperature shocks than that in richer countries. Also, Newell et al. (2021) came to the conclusion that income levels play an important role in the distribution of the negative impacts of temperature changes. However, Burke et al. (2015) found that rich and poor countries alike suffer from global warming and that the growth of agricultural and industrial sectors is hindered.

Table 8. The estimation results of SUR (developed countries).

Variables	D1	D2	D3	D4
Agriculture: $Ag_{it} = \alpha_0 + \alpha_1 hc_{it} + \alpha_2 pop_{it} + \alpha_3 tmp_{it} + \alpha_4 pr_{it} + \xi_{it}$				
population growth	***−4.6 (0.000)	***−0.67 (0.000)	**−1.91 (0.01)	0.13 (0.25)
Urbanization rate	0.03 (0.26)	0.52* (0.07)	0.1 (0.12)	***0.28 (0.000)
Human capital	0.06 (0.45)	***0.36 (0.000)	0.02 (0.23)	***0.41 (0.000)
temperature	***−0.15 (0.000)	**−0.04 (0.03)	***−0.35 (0.000)	***−0.39 (0.000)
rainfall	***0.13 (0.000)	***0.31 (0.000)	***0.79 (0.000)	***3.6 (0.000)
constant	−1.69 (0.99)	−1.02 (0.99)	1.48 (0.99)	2.52 (0.99)
Manufacturing: $Mn_{it} = \alpha_0 + \alpha_1 hc_{it} + \alpha_2 pop_{it} + \alpha_3 tmp_{it} + \alpha_4 pr_{it} + \psi_{it}$				
population growth	***−2.85 (0.000)	***−0.4 (0.000)	***−1.16 (0.008)	0.11 (0.11)
Urbanization rate	0.03 (0.48)	−0.16 (0.73)	0.03 (0.78)	***0.73 (0.53)
Human capital	0.02 (0.88)	***0.61 (0.000)	0.03 (0.35)	***0.61 (0.000)
temperature	***−0.27 (0.000)	***−0.09 (0.009)	***−0.58 (0.000)	**−0.27 (0.01)
rainfall	0.22 (0.12)	0.43 (0.21)	***0.48 (0.000)	***0.73 (0.000)
constant	−5.5 (90.99)	−5.21 (0.99)	3.32 (0.99)	−1.75 (0.99)
Services: $Sr_{it} = \alpha_0 + \alpha_1 hc_{it} + \alpha_2 pop_{it} + \alpha_3 tmp_{it} + \alpha_4 pr_{it} + \delta_{it}$				
population growth	***−0.73 (0.000)	***−0.11 (0.000)	***−0.4 (0.006)	0.01 (0.4)
Urbanization rate	−0.0007 (0.93)	**0.15 (0.05)	0.006 (0.77)	***0.11 (0.000)
Human capital	−0.014 (0.54)	***0.11 (0.000)	0.002 (0.67)	***0.08 (0.000)
temperature	***−0.05 (0.000)	***−0.02 (0.000)	***−0.1 (0.000)	**−0.03 (0.01)
rainfall	0.038 (0.31)	0.06 (0.19)	***0.24 (0.000)	****0.8 (0.000)
constant	−6.13 (0.99)	−9.05 (0.99)	7.6 (0.99)	−5.74 (0.99)
R 2	0.19	0.4	0.58	0.66
adj R 2	0.18	0.38	0.53	0.66

Source: Research findings.

The findings show that the effects of different variables on different sectors are not the same. Human capital impacts industry most while it affects agriculture less. Rainfall has had the greatest impact on the agricultural sector in all frequencies, and similarly, the negative effects of population growth have had the greatest impact on the agricultural sector. As far as the effects of climate are concerned, the agricultural sector has the most adverse effect from the decrease in rainfall compared to the increase in temperature. The severe effects of climate change on agriculture have been highlighted in previous studies such as Mendelshon et al. (2006) In industry and service sectors, rainfall has a negligible effect on economic growth. Furthermore, both the industry and service sectors, like the agriculture sector, are negatively affected by the increase in temperature.

Table 9. The estimation results of SUR (developing countries).

Variables	**D1**	**D2**	**D3**	**D4**
Agriculture: $Ag_{it} = \alpha_0 + \alpha_1 hc_{it} + \alpha_2 pop_{it} + \alpha_3 tmp_{it} + \alpha_4 pr_{it} + \xi_{it}$				
population growth	**−0.94 (0.04)	−0.17*** (0.005)	−0.91 (0.23)	−0.65 (0.11)
Urbanization rate	0.11 (0.31)	0.18 (0.12)	0.21 (0.32)	**0.18 (0.04)
Human capital	*0.12 (0.07)	0.09 (0.35)	0.15 (0.51)	***0.24 (0.008)
temperature	***−0.34 (0.000)	***−0.21 (0.00)	***−0.41 (0.004)	**−0.48 (0.02)
rainfall	***0.39 (0.04)	0.25* (0.08)	***0.54 (0.000)	***1.73 (0.000)
constant	−23.09 (0.81)	−18.44 (0.93)	−12.41 (0.93)	5.68 (0.93)
Manufacturing: $Mn_{it} = \alpha_0 + \alpha_1 hc_{it} + \alpha_2 pop_{it} + \alpha_3 tmp_{it} + \alpha_4 pr_{it} + \psi_{it}$				
population growth	**−1.33 (0.023)	***−1.15 (0.000)	−0.76 (0.478)	−0.41 (0.19)
Urbanization rate	***0.19 (0.001)	0.57 (0.47)	0.27 (0.62)	***0.75 (0.004)
Human capital	**3.51 (0.01)	***2.47 (0.000)	**0.98 (0.012)	***2.58 (0.000)
temperature	***−0.27 (0.000)	***−0.41 (0.009)	−0.58 (0.37)	−0.74 (0.24)
rainfall	0.08 (0.14)	0.03 (0.18)	0.21 (0.45)	0.27* (0.06)
constant	42.23 (0.84)	−41.3 (0.84)	18.32 (0.90)	−40.09 (0.90)
Services: $Sr_{it} = \alpha_0 + \alpha_1 hc_{it} + \alpha_2 pop_{it} + \alpha_3 tmp_{it} + \alpha_4 pr_{it} + \delta_{it}$				
population growth	***−1.63 (0.000)	−1.65 (0.18)	***−2.12 (0.006)	**−1.34 (0.02)
Urbanization rate	*−0.04 (0.09)	0.006 (0.15)	0.02 (0.43)	***0.09 (0.009)
Human capital	**0.25 (0.01)	0.24 (0.54)	**0.18 (0.05)	**0.15 (0.04)
temperature	−0.11 (0.32)	−0.09 (0.54)	***−0.12 (0.000)	**−0.14 (0.000)
rainfall	0.14* (0.08)	0.19 (0.19)	***0.34 (0.000)	0.59* (0.09)
constant	23.16 (0.98)	8.05 (0.98)	11.63 (0.98)	−23.6 (0.98)
R 2	0.27	0.44	0.47	0.58
adj R 2	0.25	0.40	0.44	0.55

Source: Research findings *, ** and *** indicate significance levels at 10%, 5% and 1% respectively.

Table 9 shows the estimated SUR for developing countries. The findings indicate that human capital positively affect all sectors of GDP in medium and long terms. Human capital has less effect in agriculture sector while has more effects in manufacturing and services sectors as compared to that of developed countries. The temperature has a negative and significant effect on agriculture sector in all frequencies while it has a negative and significant effect on industry sector in short and medium terms and has a negative and significant effect on services sector only in the long term. These results are in line with Desbordes and Eberhardt (2024). They indicated that in low-income or high-temperature countries, there is a negative relationship between temperature and income per capita. Rainfall has had the greatest impact on the agricultural sector in all frequencies while magnitude of this effect is less as compared to that of developed countries. Damania et al. (2020) concluded the relationship between rainfall and GDP growth is sharper in low-income countries. Also, they found a concave relationship between rainfall and GDP per capita growth, implying that rainfall first increases economic growth at a decreasing rate and then till it reaches a peak beyond which the economic growth declines with the increase of rainfall.

5. Conclusion

This research has examined the relationship between climate change and economic sectors for the economies of developed and developing countries. In order to achieve the mentioned goal, a wavelet-based SUR model was estimated for the period 2000–2021. The findings indicated that temperature and rainfall have a significant negative and positive relationship with the added value of agriculture, industry and services sectors, respectively. But severity of the negative effects is greater in the agricultural and industrial sectors in all frequencies of developed and developing countries compared to service sector. Furthermore, the severity of the positive effects is greater in the agricultural sector in all frequencies of developing countries compared to the industrial and service sectors. Developing countries are more vulnerable to climate change in all sectors compared to developed countries.

The results also indicated that the climate change affects the economic sectors and this impact is more on the sectors that are more interconnected with the agricultural sector. According to the obtained results, climate change and warming can have serious risks for reducing the added value of the agricultural sector, and naturally, the decrease in the income of this sector will reduce the motivation for production, and this in turn can have indirect effects on the business model, development and food security.

Currently poor countries may become even poorer due to the negative impact of climate change. Hsiang et al. (2017) documented a similar result. Taking the United States as an example, they found that the underlying climate risk is increasingly unevenly distributed across regions, and that climate damage in poorer regions may increase by the year 2100, up to 20 percent of their GDP. As a result, climate change plays an important role in maintaining the income gap between developed and developing regions at both the global and national levels (Diffenbaugh and Burke, 2019).

Governments should consider the differential impacts of climate change on economic sectors when restructuring industries. In particular, the negative impact of global warming can be reduced by taking effective measures: for agriculture, relevant officials and employees can better understand and identify the risks of climate change, and invest research and development in agricultural production and technology while the negative effects of global warming on industry and services can be mitigated by stimulating investment and promoting adaptation, including increasing air conditioning systems, network intensification urban drainage and upgrading of smart services. The obviously negative climate-economy relationship strongly indicates that the government should promote public awareness of the effects of climate change and positively face the challenges of global warming through mitigation and adaptation. In fact, as global warming impact all countries international collaboration, through substantial financial resources and investments, is required to mitigate the impacts of climate change. Also, adaptation, as an important tool for long-term economic growth, is the best way to reduce the negative effects of climate change. Finally, the governments should do best to minimize greenhouse gas emissions by using alternative energy sources.

The prospects of this research are as follows: First, this research examines the impact of climate change on economic growth at the macro level. A future study could focus on this relationship at the micro level, ISIC codes in economic sectors. Second, since climate change is a global phenomenon that exceeds the geographic borders of countries, the spatial impacts of climate change on economic sectors including agriculture, industry and services, using a panel of all countries or a panel of different countries in a continent, is suggested for future research. To examine these spatial effects in different frequencies, a hybrid spatial wavelet-based SUR model is proposed.

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