Iranian Economic Review, 30(2), 540-574
DOI: https://doi.org/10.22059/ier.2024.373094.1007948

RESEARCH PAPER

Heterogeneous Effects of Climate Change on Output across the Manufacturing Subsectors in Nigeria

Oluwasegun Olawale Benjamin[a,*], and **Victoria Oluwatoyin Foye**[b]

a. Research and Data Analysis Department, Lightway Research and Technology Centre, Ilorin, Nigeria.
b. Department of Economics, Faculty of Economics and Management Sciences, University of Ibadan, Ibadan, Nigeria.
* Corresponding author.

Received: 26 Feb. 2024, Revised: 19 April 2024, Accepted: 23 May 2024, Published: 30 June 2026
Publisher: The University of Tehran Press.

Abstract

Climate change remains a global issue despite the efforts of international organizations to combat dangerous global warming, especially in developing countries like Nigeria. Therefore, this study aims to analyze the heterogeneous effects of climate change on output across the manufacturing subsectors in Nigeria from 1990 to 2021. The fully modified ordinary least squares method is used to analyze the time series data, and canonical cointegrating regression, along with diagnostic tests (normality and Wald restriction tests), are conducted to check the robustness of the models. The empirical results reveal that climate change has a significant negative effect on manufacturing output at the aggregate level and across the manufacturing subsectors. The adverse effect is particularly strong for Textile, Apparel and Footwear, Plastic and Rubber Products, and Chemical and Pharmaceutical Products subsectors. Moreover, the study finds that manufacturing output at the aggregate level and across manufacturing subsectors responds negatively to the exchange rate and positively to labor and capital. Based on the results, the study recommends that the government discourage fossil fuel consumption and promote renewable energy consumption such as solar, wind, hydropower, and geothermal power, to slow climate change. Additionally, the government needs to implement structural reforms to reduce reliance on foreign inputs and final products, enhance domestic production and exports, increase foreign reserves, and strengthen the Nigerian currency.

Keywords: climate change, environmental impact, fully modified ordinary least squares, manufacturing sector, sustainable development.

JEL Classification: L61, L65, L66, L600, Q540.

Introduction

Climate change remains a global challenge despite the renewed efforts of international organizations to combat dangerous global warming, especially in developing countries. The macroeconomic consequences of climate change, resulting from the inability to address its negative impact, have gained a great deal of attention from researchers and dominated the discussion of policymakers. Climate change lowers African countries' growth and development (Baarsch and Schaeffer, 2019) and different studies have established the negative effect of rising climate conditions on economic growth, especially in developing countries (Farajzadeh et al., 2023; Khurshid et al., 2022; Kahn et al., 2021). Existing studies have also investigated the impact of climate change on labor supply and productivity (Dasgupta et al., 2021; Somanathan, et al., 2021; Cai et al., 2018) and different sectors of the economy, especially the agricultural sector (Anh et al., 2023; Tajudeen et al., 2022; Van Huong et al., 2022) and manufacturing sector (Kabore and Rivers, 2023; Foye and Benjamin, 2021; Chen et al., 2020). The limited studies on climate change-manufacturing sector nexus, however, paid no or lesser attention to the heterogeneity of the manufacturing sector, especially in Africa. Changes in climate impact the different manufacturing sub-sectors and the magnitude of the effect varies according to the share of the workforce employed, energy and water resources demand, technology (machine) use and dependency on agro products and raw materials, largely driven by changes in weather (Foye and Benjamin, 2021; Zhang et al., 2018; Murphy and Harris, 2014). It is therefore crucial for policymakers to understand the impact of climate change on the manufacturing sector in general, the differential magnitude of the effect on sub-sectors and the underlying causes of the differences. This is the focus of this study.
For decades, the manufacturing sector has been recognized as the engine of economic growth and the path to economic development (Haraguchi et al., 2016). The manufacturing sector generates productive jobs through its direct backward linkage to different sectors such as the mining and construction and forward linkages to the transportation and other sectors of the economy (Herman, 2016). For instance, the manufacturing sector generates employment opportunities in the mining and construction industry by stepping up its demand for their services. In like manner, the employment effect of the forward linkage of the manufacturing sector to transportation, wholesale, retail trade and business services occurs as a result of the increasing demand for manufacturing outputs. In addition, manufacturing offers relatively high wages and unique opportunities for capital accumulation. It also serves as a key source of investment in research and development, which are very critical for education and innovation.

Furthermore, the manufacturing sector contributes greatly to the improvement in the export capacity of an economy. The sector transforms raw materials to finished goods which are exported to other parts of the world and hence increases export earnings. According to extant research, export earnings are very important in the growth and development process of both developed and developing economies (Adaramola, 2016; Osabohien et al., 2019; Kalaitzi and Chamberlain, 2020). In fact, the export-led growth hypothesis argues that export, most notably manufacturing exports act as a catalyst for economic growth. This is because it boosts employment, productivity, foreign reserves, and ensures a favorable balance of trade. In countries like Taiwan, India, Singapore, South Korea, China and Hong Kong, manufacturing sector has been a center piece of development policies. These countries have used the sector to fast-track their economic growth and development (Orji et al., 2018).

In China, manufacturing sector has been used to offer technological advancement, which diffuses to other areas of the Chinese economy and world at large. Similarly, manufacturing is an integral part of the economies of Taiwan and Singapore among others, as it has been used to uplift the Small and Medium Enterprises (SMEs) and strengthen national export capacity of the economy. Given the vital role of the manufacturing sector, the Nigerian government has introduced several measures to boost the sector and promote economic growth. Examples include import substitution industrialization which encourages local production of imported goods; the movement from a fixed exchange rate system in 1986 by introducing structural adjustment programs to strengthen the manufacturing sector; and the establishment of the Bank of Industry to address funding problems for small and medium scale enterprises, among others. Despite the policy attention the sector has been receiving, the performance of the sector has been less than satisfactory. The poor performance of the sector has been attributed to a number of factors including climate change (Kabore and Rivers, 2023; Foye and Benjamin, 2021). For instance, manufacturing sector output, as a percentage of GDP improved to 19.74% and 18.24 in the 80s and 90s respectively, up from a meagre 5% in the 60s and 70s, probably due to adoption of SAP. However, it declined to 9.85% and 9.42% in the last two decades. These statistics cannot be compared to China and Singapore whose outputs are more than double in the same period.

Global climate change has been on the increase in the recent time. Since 1970, the surface temperature across the globe has risen more than in any other 50-year period over the last 20 years. Between 2001 and 2020, the global surface temperature was 0.99 degree Celsius higher than what was recorded between 1850 and 1900. In the third quarter of the year 2023, specifically, in September, the average temperature of the world was 1.8 degree Celsius and by the end of the fourth quarter, the year is expected to be the warmest year ever (Intergovernmental Panel on Climate Change [IPCC], 2023). Changes in the climatic conditions affect variety of human activities (Jakada and Mahmood, 2023) and has great impact on the climate-exposed sectors, including manufacturing sector (Chen et al., 2023; Khurshid et al., 2022). According to Khurshid et al. (2022), an increase in daily temperature by one degree Celsius reduces economic growth by 5% in any given year. The reliance of African countries, on the environment makes it highly vulnerable to the impacts of climate change, with weaker nations in the region facing heightened risks of decline in economic growth (Aryeetey and Baffour, 2022), despite contributing the least to global greenhouse gas emissions (African Development Bank Group [AfDB], 2019). The detrimental effect of climate change on developing countries like Nigeria can be attributed to three factors (Dietz and Millner, 2015). First, the geographical location of the developing countries exposed them to the frequent change in the rising temperature, water level and rainfall caused by the changes in the climate. Second, the developing countries depend largely on sectors that are highly influenced and sensitive to climate change. Third, developing countries lack the ability to adapt due to their geographical location, sensitivity to climate change, lack of resources, weak institutions, and poor infrastructure.

Nigeria is Africa's largest economy and one of the ten countries vulnerable to seasonal variability and long-term climate change. The country has three different climate zones, tropical wet climate (south), tropical savannah climate (central), and Sahelian hot and semi-arid climate (north), with an average annual temperature of 27.2 degree Celsius (World Bank, 2021). Nigeria experiences extreme heat during the dry season and records the highest increase in temperature in the northern region. Between 1901 and 2016, the country records a 0.03-degree Celsius increase in temperature per decade, with a higher increase of 0.19 degree Celsius per decade in the last 30 years and by 2060, Nigeria is projected to experience between 1.1- and 2.5-degree Celsius increase in temperature (World Bank, 2021; United States Agency International Development [USAID], 2019). Climate change has a strong impact on Nigerian sectors, including manufacturing sectors which is key to broader growth and the strong dependence of the country on these sectors could result to about 6% to 30% decrease in economic growth, that is, US$100 to 460 billion losses by 2050 (World Bank, 2021; USAID, 2019). Given this situation, there is a need to investigate the effect of climate change on the manufacturing sector in Nigeria as this will enable the policymakers to formulate policies that will reduce the adverse impact of climate change and boost the performance of the manufacturing sector in Nigeria.

A few studies have examined the nexus between climate change and manufacturing sector and they alluded to the detrimental effect of climate change on manufacturing sector (Kabore and Rivers, 2023; Foye and Benjamin, 2021; Chen et al., 2020; Fatusin et al., 2019). However, the studies on the impact of climate change on manufacturing sector in Nigeria are sparse and they either focus on the aggregate manufacturing output (Foye and Benjamin, 2021) or are conducted in a specific state (Fatusin et al., 2019). Seasonal variability and long-term climate change may exert diverse impact on the manufacturing subsector and suitable policies cannot be formulated based on the findings of the existing studies. In summary, the impact of climate change on manufacturing sector has not been well researched in Nigeria. This appears to be the first study to analyze the response of manufacturing subsector output to the changes in climatic conditions in Nigeria. This study contributes to knowledge in three folds: First, it is very clear from the literature that none of them have investigated the effect of climate change on the manufacturing subsectors in Nigeria. This study, therefore, analyze the effect of climate change on the 12 manufacturing subsectors in Nigeria. Secondly, the existing studies use different methodologies, including error-correction method, linear and non-linear autoregressive distributional lag, generalized method of moments, panel autoregressive distributed lag, generalized least squares technique, ordinary least squares regression method, fixed-effects ordinary least squares, panel fixed effects technique, and partial least squares regression methods but none of the existing studies utilize Fully Modified Ordinary Least Squares to analyze the response of manufacturing subsectors to climate change. This technique is robust and it accounts for the effects of possible endogeneity of the regressors. Also, it corrects ordinary least squares serial correlations problem and provides long-run estimates. Thirdly, this study uses the most recent data to analyze the effect of climate conditions. Foye and Benjamin (2021), who previously conducted a similar study used only value added to measure manufacturing sector growth in Nigeria. In addition to using a robust technique and considering the 12 subsectors of the sector, this study distinguished itself by using two different manufacturing sector measures.

The remaining part of the paper is organized into four sections. The paper reviews the literature in section two and presents model specification, techniques of analysis, sources and measurement of data in section 3. Section 4 comments on the empirical results and discussion while section 5 concludes the study and provides policy implications.

Literature Review

Researchers around the world have studied the impact of climate change in developed, emerging and developing economies and there is reasonable consensus in the literature that rising temperature has a detrimental effect on economic growth, especially in developing countries. Ogbuabor and Egwuchukwu (2017) investigated the effect of climate conditions on the economic growth in Nigeria over the period of 1981 to 2014 and the results of the ordinary least squares method showed that climate change affects the Nigerian economy adversely in the short and long run. Sequeira et al. (2018) analyzed the global effect of climate change across the world from 1950 to 2014. Based on the results of the error-correction model approach, the study submitted that increases in temperature and precipitation have a non-significant effect on long run growth while the effect of precipitation is marginally significant and positive in the short run. In addition, the study reported that higher temperature has a negative effect on poor countries growth while precipitation has a positive effect. In a similar study, the effects of climate change on economic growth of the top 20 countries in the world was estimated by Kadanali and Yalcinkaya (2020) from 1990 to 2016 using panel autoregressive distributed lag (linear and nonlinear) and two stage least squares regression. The findings of the study showed that climate change has adverse effect on economic growth. Foye (2020) explored the effect of population and climate change on the growth of Nigerian economy from 1981 to 2017 and the results reaffirmed the detrimental effect of climate change on economic growth. Using subnational data of 1,500 regions in 77 countries, Kalkuhl and Wenz (2020) concluded that global output decreases with the increase in the global climate change, especially in the tropical and poor regions. Kahn et al. (2021) examined the long run effect of the climate change on economic growth of 174 economies from 1960 to 2014 using an ordinary least squares regression method. The results indicated that continuous changes in the temperature impacted the growth of the 174 countries negatively. Birnintsaba et al. (2021) utilized autoregressive distributed lag method to reaffirm the negative effect of climate change on economic growth in Nigeria over the period of 1971 to 2014. Furthermore, Khurshid et al. (2022) analyzed the climate change effect on Pakistan's economic growth from 1980 to 2021 and the empirical findings revealed that climate change has asymmetric effect on growth, with positive temperature having a positive impact on growth and negative temperature having a negative effect on growth. Farajzadeh et al., (2023) used a generalized method of moments to analyze the impact of rising climate conditions on economic growth of Asian economies from 1994 to 2017 and the authors reported that climate change has detrimental effect on the Asian countries' economic growth.

Scholars have also investigated the influence of climate change on workers and labor allocation in different countries. Cai et al. (2018) examined the influence of temperature on the worker productivity of the manufacturing sector in China. The study utilized a regression technique to analyze the primary data obtained from 61 workers, 77 machines and 23 products from October 2012 to February 2014 and the empirical findings revealed an inverted-U shape relationship between temperature and labor productivity. At micro-level, Huang et al. (2020) utilized the hedonic approach to analyze a panel of field survey data obtained from 8076 working age residents in 279 rural communities in China, with the view of estimating the effects of climate change on the labor market in the long run. The study submitted climate change lowers the time allocated to farming and leisure by rural dwellers and increases the off-farm work time. Furthermore, the world subnational regions' micro-survey data was used by Dasgupta et al. (2021) to explore the response of productivity and supply of labor to climate change. The findings showed that labor effectiveness is negatively affected by current climate change, especially in the tropical countries. Also, the empirical evidence suggested that future climate conditions reduce the supply of labor and productivity in the tropical regions.

Several studies have alluded to the detrimental effect of climate change on different industries or sector across the globe, including the industrial and manufacturing sector. Chen and Yang (2019) investigated the effect of temperature on industrial output in China with panel data of 530,370 firms in 31 provinces. The regression results suggested that industrial output is influenced positively by rising spring temperatures and negatively by higher summer temperatures. In addition, the study submitted that the response of output to rising summer temperatures in high-temperature regions is low compared to low-temperature regions. At micro-level, Fatusin et al. (2019) assessed the impact of climate change on the growth of agro-based small scale industries in Ondo state Nigeria. The study analyzed the data collected from 200 enterprises with a Pearson moment correlation method to establish detrimental effect of climate change on many small-scale enterprises in the state. In the United States, Colacito et al. (2019) examined the interaction between climate change and growth from 1957 to 2012. The study also analyzed state and industry-level data and they found that decline in the aggregate, state and industries output is associated with climate change. Using partial least squares regression method, Chen et al. (2020) assessed the effect of climate change on the outputs of the manufacturing in Nanjing, China from 1985 to 2013. They confirmed that rising temperature and precipitation have detrimental effect on manufacturing sector output. In Nigeria, Foye and Benjamin (2021) estimated the relationship between rising climate conditions, technological progress and manufacturing performance over the period of 1970 to 2016 using a structural vector autoregressive. The authors alluded to the detrimental effect of climate change on the growth of the manufacturing sector in Nigeria.

Moreover, Hernandez and Madeira (2022) employed a fixed-effects ordinary least squares approach to analyze the influence of climate change on 12 different industries in Chile from 1985 to 2017. The results of their analysis are mixed. While the study established a negative effect of climate change on agriculture, fishing, manufacturing, energy-gas-water, construction and commerce, the effect on mining, finance and personal services was positive. Also, Foye (2022) probed the impact of climate change on macro prices in Nigeria over the period of 1960 to 2019 using the nonlinear autoregressive distributed lag approach. The study submitted that climate conditions in Nigeria has more adverse effect on food prices. Van Huong et al. (2022) used autoregressive distributed lag to analyse Vietnam's annual data from 1990 to 2020 and the results of the analysis showed that climate change harms agricultural production in the long and short run. Using autoregressive distributed lag and time series data spanning from 1990 to 2019, Anh et al. (2023) also found a negative relationship between global warning and the performance of the agricultural sector in Vietnam. Moreover, Kabore and Rivers (2023) explored the nexus between extreme temperature and manufacturing output in Canada from 2004 to 2012 and the empirical evidence from the panel fixed effects technique showed a negative relationship between temperature and the output of the manufacturing sector. Also, Chen et al. (2023) used an individual-level data to investigate the effect of climate change on the productivity of the wafer manufacturers in China. The results obtained from the regression analysis suggested a negative relationship between climate change and silicon wafer maker in China. Prior studies have also documented the effect of climate change on multiple industries in different nations.

It is obvious from the studies reviewed that several scholars have queried the influence of climate change on economic growth and different sectors of the economy, including manufacturing sector, especially in the emerging and developed nations. However, the literature is sparse on the effect of climate change on manufacturing sector heterogeneity in Nigeria. The only studies on climate change-manufacturing nexus in Nigeria focused either on aggregate manufacturing output (Foye and Benjamin, 2021) or agro-based small scale industries in one of the states in Nigeria (Fagbohunka, and Yoade, 2019). In addition, none of the prior studies reviewed utilized Fully Modified Ordinary Least Squares to investigate the impact of climate change. This study fills a gap in the literature by analyzing the effect of climate change on the manufacturing sector as a whole and its subsectors to control better for individual peculiarities.

Methodology

Theoretical Framework and Model Specification

The neoclassical growth theory proposed by Solow (1956) forms the basis of the estimated models in this study. This growth theory is also known as Cobb-Douglas production function and it demonstrates the response of output to the changes in the factors of production. In other words, the Cobb-Douglas production function explains how capital, labor and technology drive the increase in output. The basic Cobb-Douglas production function is presented as follows:

$$Y_t = K_t^{\alpha} \cdot A_t L_t^{\beta} \tag{1}$$

where output is denoted by Y, capital is represented by K, labor is L, labor productivity is denoted by A and the subscript t stands for time series. The elasticity of output with respect to capital and labor also known as the share of capital and labor in output is denoted by α and β, respectively. The addition of the share of capital and labor in output yield is one (1), suggesting that the Cobb-Douglas production function exhibits constant returns to scale, that is, $\alpha + \beta = 1$. This is not the first study that relies on the Cobb-Douglas production model. A great number of empirical studies on the effects of climate change on economic growth and manufacturing sector performance have also followed the same approach (Farajzadeh et al., 2023; Foye and Benjamin, 2021; Hoang and Huynh, 2021; Kahn et al., 2021; Kadanali and Yalcinkaya, 2020; Foye, 2018; Akram, 2013).

According to Farajzadeh et al. (2023) and Akram (2013), climate change has direct and indirect effects on output. The direct effect is also known as the level effect, while the indirect effect of climate change on output comprises two channels, which are depreciation of capital and reduction in productivity growth. Following Farajzadeh et al. (2023) and Akram (2013), who added climate change as an input that has a direct effect on output, this study specifies the estimated model with the exchange rate as a control variable as follows:

$$Y_{tm} = A_t CAP_t^{\alpha} LAB_t^{\beta} CCH_t^{\delta} EXC_t^{\varphi} \quad (2)$$

Equation 2 is a nonlinear model. The study takes the natural logarithm (ln) of all the variables to obtain a linear model, avoid potential heteroscasticity problems and easily interpret the results (Benjamin et al., 2023). The linear version of Equation 2 is expressed with error term (μ) as follows:

$$\ln Y_{tm} = \phi + \alpha \ln CAP_t + \beta lnLAB_t + \delta \ln CCH_t + \varphi \ln EXC_t + \mu_t \quad (3)$$

where Y stand for the manufacturing output, m = 0, 1, 2, 3, …, 12; 0 is the aggregate manufacturing output or value added while 1, 2, 3, ..., 12 stands for the 12 manufacturing subsectors output. The study estimates the effect of climate change on the manufacturing value added and aggregate output. Next, the study disaggregated the manufacturing output into 12 with each representing each subsector. These subsectors are oil refining (OLR), cement (CEM), food, beverage and tobacco (FBT), textile, apparel and footwear (TAF), wood and wood products (WWP), pulp, paper and paper products (PPP), chemical and pharmaceutical products (CPP), non-metallic product (NMP), plastic and rubber products (PRP), electrical and electronics (EEL), basic metal, iron, and steel (MIS), and motor vehicles and assembly (MVA). CAP is capital, LAB stands for labor, CCH is climate change, and EXC represents exchange rate. Constant is denoted by ϕ, white noise is depicted by μ_t while the parameter of capital, labor, climate change, and exchange rate is represented by α, β, δ, and φ, respectively.

With regard to the a priori expectations, capital, labor, exchange rate are expected to have a positive effect on manufacturing output, climate change is expected to have a negative relationship with manufacturing output, while exchange rate has a negative relationship with manufacturing output. These a priori expectations are presented in mathematical format as $\alpha, \beta, \varphi > 0; \delta < 0$, respectively. The theoretical relationship between output, capital, and labor is well documented in the literature (Zhu et al., 2022; Foye and Benjamin, 2021). Capital investment is very crucial to the growth of every sector, including manufacturing sector. Physical capital such as plant and equipment, infrastructure, among others improve production process and enhances the sector's production capacity. Hence, greater capital translates to more output (Zhu et al., 2022). Labor is also as crucial as capital because it boosts output and value-added. Humans provide the intellectual skills required for production, as well as packaging, sales, and distribution of final output. An improvement in workers' intellectual capacity therefore enhances production process and boost workers' productivity. As workers' productivity increases, more goods and services are produced and output level increases (Zhu et al., 2022; Foye and Benjamin, 2021).

Climate change is a global issue with adverse effects on output. The rise in the temperature level as a result of the concentration of greenhouse gases in the atmosphere increases the heat waves (Benjamin et al., 2023), which affect the production capacity of firms and reduce the level of output. Also, warmer climate affects workers' productivity by causing discomfort and fatigue and limiting the hours workers spend in producing goods and services (Chen, 2023; Farajzadeh et al., 2023; Foye and Benjamin, 2021). More so, higher temperatures affect the functionality of manufacturing equipment (Foye and Benjamin, 2021) and lower the output level. Similarly, climate change leads to an increase in sea level (Benjamin et al., 2023; Jakada and Mahmood, 2023; Cho, 2019) which could damage the assets of manufacturing companies, especially firms that are located in riverine areas, thereby reducing firms' output levels. In summary, climate change results in lower output.

Exchange rate is expected to have a positive impact on manufacturing output. This is because exchange rate depreciation raises the prices of imported goods relative to locally produced goods. The higher prices of foreign goods make them costly to purchase and this reduces total spending on foreign goods while spending on domestic goods increases. The end result is an increase in aggregate demand, exports and manufacturing output (Akpan and Atan, 2011; Kandil and Mirzaie, 2005).

Estimation Strategy

The classical estimation methods assume that the means and variances of macroeconomic variables are not a function of time. But in most cases, macroeconomic variables have unit roots, which implies that the means and variances change with time. The presence of unit roots in macroeconomic variables leads to the spurious regression problem and misinterpretation of the empirical findings when classical techniques of estimations, including Ordinary Least Squares are applied (Nasreen et al., 2017). To avoid these problems and determine the most appropriate estimation technique, this study uses Augmented Dickey Fuller (ADF) proposed by Dickey and Fuller (1979) and Phillip Peron (PP) developed by Phillips and Perron (1988) to examine the stationarity features of the time series data. The ADF is often referred to as a conventional unit root test and the null hypothesis (H0) is $\rho = 1$ while the alternative hypothesis (H1) is $\rho < 1$.

This conventional unit root test is deficient because the estimated results are inefficient in the case of small sample and this inadequacy can be attributed to the size and properties of the test (Nasreen et al., 2017).

Phillips and Perron (1988) propose a non-parametric unit root test. The null hypothesis (H0) for the non-stationarity of xtxt is $\alpha = 0$ and the alternative hypothesis (H1) is $\alpha < 0$. This test is superior to ADF because it addresses the problems of serial correlation and heteroskedasticity in the residuals of the regression test. Next, the study conducts vector autoregression (VAR) lag selection with preference for Schwarz Information Criterion (SIC) to determine the optimum lag length for the co-integration test and regression. This is essential because inappropriate lag selection will result in model misspecification. Moreover, the study selects SIC to obtain the optimum lag length because it is suitable when the sample size is small, as in the case of this study and the variables of interest are greater than three (Naseem et al., 2023; Neath and Cavanaugh, 1997; Cavanaugh and Neath, 1999). According to Kheifets and Phillips (2023), a set of variables that are non-stationary and integrated at first difference (I(1)) form an equilibrium relationship in the long run if their lower order series is integrated of order zero (I(0)). This study uses Johansen's maximum eigenvalue and trace cointegration tests proposed by Johansen (1988; 1991) to establish the long run association among the variables.

In the presence of long-run relationships, the ordinary least squares (OLS) regression method becomes unreliable because it does not address the problems of endogeneity and serial correlations (Pedroni, 2001). These problems are corrected by fully modified ordinary least squares (FMOLS) and as a result, FMOLS produces unbiased estimates of the long run coefficients (Olaifa and Benjamin, 2020). Also, unlike OLS, FMOLS does not difference non-stationary variables because of its suitability when all variables are integrated at first difference. This makes it possible for FMOLS method to keep records of the co-integrating properties inherent in the levels of the time-series (Perman, 1991). Given these unique benefits, this study utilizes the FMOLS developed by Phillips and Hansen (1990) to analyze the impact of climate change on the manufacturing sector in Nigeria. To validate the results of FMOLS, the study utilizes canonical cointegrating regression (CCR) estimation method as a robustness check technique and also conducts normality tests and a Wald restriction test.

Data

To analyze the effect of climate change on manufacturing sector heterogeneity in Nigeria, the study uses time series data from 1990 to 2021. The measures of manufacturing sector are manufacturing value-added (constant local currency) and manufacturing output at 2010 constant basic prices. Capital is measured with gross fixed capital formation (constant local currency) and for labor, the study uses labor force. Annual average temperature is used to measure climate change and the official exchange rate (constant local currency per US$, period average) is used for the exchange rate. Moreover, annual average output at 2010 constant basic prices is used to measure each of the 12 subsectors, and the data, including aggregate manufacturing output, are obtained from the Central Bank of Nigeria (2022). The 12 manufacturing subsectors are oil refining; cement; food, beverage and tobacco; textile, apparel and footwear; wood and wood products; pulp, paper and paper products; chemical and pharmaceutical products; non-metallic products; plastic and rubber products; electrical and electronics; basic metal, iron, and steel; and motor vehicles and assembly. Data for manufacturing value-added, gross fixed capital formation, labor force, and official exchange rate are obtained from World Development Indicators (2023) while annual average temperature is obtained from World Bank Climate Change Knowledge Portal (2023). Table 1 summarizes the descriptive statistics of all the level variables.

Empirical Results and Discussion

Unit Root

The results of ADF and PP reported in Table 2 indicate that the means and variances of all the dependent and independent variables change with time at level but remain constant at first difference. In other words, all the variables are level non-stationary and stationary at first difference. Specifically, it is observed that all the variables are integrated of order 1 [I(1)]) at ≤ 0.05 level of significance while only the natural log of chemical and pharmaceutical products (LNCPP) is significant at ≤ 0.10 level. Hence, the study rejects the null hypotheses of ADF and PP unit root tests and concludes that all the variables are integrated after taking the first difference, that is, I(1).

Table 2. ADF and PP Unit Root Tests Results

Variable	Phillips-Perron				Augmented Dickey-Fuller			
	Level		First Difference		Level		First Difference	
	Stat.	Prob.	Stat.	Prob.	Stat.	Prob.	Stat.	Prob.
LNMNO	-0.422	0.893	-3.722	0.009***	-0.080	0.943	-3.736	0.009***
LNMVAA	-0.422	0.893	-3.722	0.009***	-0.080	0.943	-3.736	0.009***
LNCEM	-0.351	0.906	-4.480	0.001***	-0.099	0.941	-4.490	0.003***
LNCPP	-0.121	0.938	-2.737	0.080*	-0.204	0.928	-2.713	0.084*
LNEEL	-1.774	0.386	-4.793	0.000***	-1.601	0.470	-4.641	0.000***
LNFBT	-1.221	0.653	-5.340	0.000***	-1.221	0.653	-5.339	0.000***
LNMIS	-0.281	0.917	-4.348	0.002***	-0.046	0.947	-4.326	0.002***
LNMVA	-1.240	0.644	-3.599	0.012**	-1.384	0.576	-3.627	0.011**
LNNMP	-0.224	0.925	-3.515	0.015**	-1.149	0.682	-3.403	0.019**
LNOLR	-0.958	0.756	-3.721	0.009***	-0.433	0.891	-3.609	0.012**
LNPPP	-0.407	0.896	-3.531	0.014**	-0.499	0.878	-3.531	0.014**
LNPRP	0.019	0.953	-3.454	0.017**	-0.211	0.927	-3.410	0.019**
LNTAF	-0.716	0.828	-3.494	0.015**	-1.232	0.647	-3.384	0.020**
LNWWP	-0.314	0.912	-5.034	0.000***	-0.271	0.918	-5.034	0.000***
LNLAB	-0.208	0.927	-3.202	0.030**	-0.023	0.949	-3.422	0.018**
LNCAP	-2.515	0.122	-10.521	0.000***	-0.536	0.870	-10.467	0.000***
LNCCH	-2.546	0.115	-19.392	0.000***	-2.546	0.115	-4.670	0.000***
LNEXC	-1.947	0.307	-5.161	0.000***	-1.855	0.348	-5.159	0.000***

Source: Research finding.

Note: *, ** and *** denote rejection of the null hypothesis of unit root at 10, 5 and 1 percent level.

Selection Criterion and Cointegration

The results are presented in Table 3 and Table II (see appendix). Table 3 reports the lag associated with the response of aggregate manufacturing output and value added to capital, labor, climate change, and exchange rate. Similarly, Table II summarizes the lag of time in connection with the response of each of the manufacturing subsectors to capital, labor, climate change, and exchange rate. The SIC is selected to determine the optimum lag because the study’s sample size is small, and the number of variables exceeds three. Table 3 shows that the SIC selects 1 as the optimal lag length for manufacturing sector output and value-added models. The optimal lag length for each of the manufacturing subsectors is indicated by asterisks in Table II.

Table 3. VAR Lag Order Selection Criteria

Lag	LogL	LR	FPE	AIC	SC	HQ
			LNMNO:			
0	139.470	NA	$6.46*10^{-11}$	-9.274	-9.038	-9.199
1	268.331	204.4011	$5.16*10^{-14}$	-16.437	-15.022*	-15.994
2	300.193	39.552*	$3.81*10^{-14*}$	-16.910*	-14.317	-16.098*
3	318.641	16.539	$9.78*10^{-14}$	-16.458	-12.686	-15.277
			LNMVAA:			
0	139.470	NA	$6.46*10^{-11}$	-9.274	-9.038	-9.199
1	268.331	204.4011	$5.16*10^{-14}$	-16.437	-15.022*	-15.994
2	300.193	39.552*	$3.81*10^{-14*}$	-16.910*	-14.317	-16.098*
3	318.641	16.539	$9.78*10^{-14}$	-16.458	-12.686	-15.277

Source: Research finding.

Note: The lag length selected by the criterion is indicated by *, sequential modified LR test statistic is depicted by LR, final prediction error is denoted FPE, AIC is Akaike information criterion, SC stands for Schwarz information criterion, and HQ is Hannan-Quinn information criterion.

Furthermore, the study uses Johansen cointegration to test the null hypotheses for various rank values (r). Tables 4 and III (see the appendix) summarize the results of the Johansen cointegration test; the different rank values represent the number of cointegrating relationships in the test equation. The empirical results reject the null hypothesis of no cointegration (r = 0) at a 0.05 significance level, suggesting that a long-term relationship exists among the variables.

Table 4. Johansen Cointegration Test Results

H_0	r = 0	r ≤ 1	r ≤ 2	r ≤ 3	r ≤ 4
		LNMNO			
Eigenvalue	0.810	0.477	0.353	0.243	0.023
Trace Stat	91.331**	41.509	22.088	9.041	0.699
Max-Eig. Stat	49.822**	19.422	13.047	8.342	0.699
		LNMVAA			
Eigenvalue	0.810	0.477	0.353	0.243	0.023
Trace Stat	91.331**	41.509	22.088	9.041	0.699
Max-Eig. Stat	49.822**	19.422	13.047	8.342	0.699

Source: Research finding.

Note: ** indicates rejection null hypothesis (H_0) at 5% level, r = 0 stand for none and r ≤ 1, 2, 3, 4 represents at most 1, 2, 3, and 4, respectively. Tests the null hypothesis (H_0) of no cointegration (r=0) against the alternative hypothesis (H_1) of cointegration (r>0).

Long-run Estimates for Manufacturing Sector

Table 4 reports the long-run estimates of climate change's impact on the Nigerian manufacturing sector. Columns 2 to 5 summarize the results of the primary model (manufacturing sector output), while columns 6 to 9 present the results for manufacturing sector value added. The primary model results reveal that labor and capital have positive and significant effects on manufacturing sector output. In contrast, climate change and exchange rates negatively impact the Nigerian manufacturing sector output. By implication, labor and capital increase the level of manufacturing sector output in Nigeria. These findings align with the a priori expectations and support the postulation of the neoclassical growth theory that output responds positively to an increase in capital and labor. Furthermore, the empirical evidence conforms with previous studies suggesting that capital (Zhu et al., 2022) and labor (Zhu et al., 2022; Foye and Benjamin, 2021) enhance the level of the manufacturing sector.

Furthermore, the coefficient of climate change shows a negative and significant relationship with manufacturing sector output in Nigeria at the 5 percent significance level. This finding agrees with the a priori expectation and supports the findings of Kabore and Rivers (2023), Foye and Benjamin (2021), Kadanali and Yalcinkaya (2020), Chen et al. (2020), and Fatusin et al. (2019) that climate change hurts manufacturing sector output growth. Climate-related events such as extreme weather conditions, droughts, and flooding affect water resources (Benjamin et al., 2023; Cho, 2019; Murphy and Harris, 2014; Dietz and Millner, 2015), raw materials and energy supply (Murphy and Harris, 2014), and damage manufacturing facilities (Mortier et al., 2010; Zhang et al., 2018). The manufacturing sector depends heavily on raw materials, energy, and other essential components, and the disruption in the supply chain (Murphy and Harris, 2014) of any of these inputs by climate-related events such as extreme weather conditions and flooding delays production, increases production costs, and reduces manufacturing sector output. Also, a significant amount of water is required in the production process (Murphy and Harris, 2014) for cooling, cleaning, and other purposes, and a shortage in the supply of water as a result of the alteration of precipitation patterns by harsh weather conditions can increase manufacturing costs and weaken manufacturers' production capacity.

Table 5. FMOLS Results of the Effect of Climate Change on Manufacturing Sector

	Manufacturing Output				**Manufacturing Value Added**			
Variable	**Coef.**	**Std Err.**	**t-Stat.**	**Prob.**	**Coef.**	**Std Err.**	**t-Stat.**	**Prob.**
LNLAB	2.359	0.778	3.031	0.006***	2.359	0.778	3.031	0.006***
LNCAP	1.036	0.583	1.777	0.087*	1.036	0.583	1.777	0.087*
LNCCH	-14.247	6.563	-2.171	0.039**	-14.247	6.563	-2.171	0.039**
LNEXC	-0.250	0.137	-1.826	0.079*	-0.250	0.137	-1.826	0.079*
C	-16.018	23.283	-0.688	0.498	4.706	23.283	0.202	0.841

Source: Research finding.

Note: *, ** and *** denote significance at 10, 5 and 1 percent level.

Table 5 also shows that the exchange rate is negatively and significantly related to manufacturing sector output. This finding contrasts the theoretical prediction and the findings of Farouq and Sambo (2022), Zhu et al. (2022), Akpan and Atan (2011), and Kandil and Mirzaie (2005), but it lends credence to Awolaja and Okedina (2020) and Akinbode et al. (2019), who report that exchange rate depreciation reduces economic growth in the long run. The negative relationship between exchange rate and manufacturing sector output in Nigeria is not unexpected. This is because the Nigerian manufacturing sector relies more heavily on imported inputs than local inputs (Wolf, 2023; Uruakpa et al., 2021; U.S. Department of State, 2015), and with exchange rate depreciation, the costs of the imported inputs increase, which leads to a rise in the cost of production. These higher production costs translate to higher manufacturing product prices, which reduce demand for locally manufactured products and discourage production (Kandil and Mirzaie, 2005). To establish the accuracy of the estimates, the study modifies the empirical model by replacing manufacturing sector output with value-added, and the results are summarized in Table 5, columns 6 to 9. The results show that the estimated coefficients' signs, magnitude, and significance levels are similar to those of the primary model.

Robustness Check Results

Two different techniques are used to check the robustness of the models. First, the study re-analyses the two models using the canonical cointegrating regression (CCR) estimation technique, and the results of the CCR presented in Table 6 align with those of the fully modified ordinary least squares in Table 5, except for capital, which appears to be insignificant. The results show that labor has a significant positive effect on manufacturing output and value-added, implying that labor boosts the output and value-added of the Nigerian manufacturing sector. The results also confirm that climate change and exchange rates have significant negative effects on manufacturing output and value-added, suggesting that changes in climatic conditions and the exchange rate stimulate a decrease in Nigerian manufacturing output and value-added.

Table 6. CCR Results of the Effect of Climate Change on Manufacturing Sector

	Manufacturing Output				Manufacturing Value Added			
Variable	**Coef.**	**Std Err.**	**t-Stat.**	**Prob.**	**Coef.**	**Std Err.**	**t-Stat.**	**Prob.**
LNLAB	2.350	0.974	2.412	0.023**	2.350	0.974	2.412	0.023**
LNCAP	1.266	0.893	1.418	0.168	1.266	0.893	1.418	0.168
LNCCH	-16.311	7.524	-2.168	0.040**	-16.311	7.524	-2.168	0.040**
LNEXC	-0.275	0.135	-2.039	0.052*	-0.275	0.135	-2.039	0.052*
C	-15.704	27.671	-0.568	0.575	5.019	27.671	0.181	0.858

Source: Research finding.
Note: *, ** and *** denote significance at 10, 5 and 1 percent level.

Second, the study subjects the models estimated by FMOLS and CCR to two diagnostic tests. Specifically, the study utilizes the Jarque-Bera normality test to examine the null hypothesis that the data used for the analysis are normally distributed. The normality test results presented in Table 7 show that the Jarque-Bera statistics are not significant at the 5 percent level for fully modified ordinary least squares (columns 2 and 3) and canonical cointegrating regression (columns 6 and 7). These results imply that the null hypothesis of normality cannot be rejected at the 5 percent significance level. Furthermore, the Wald restriction test is used to test the null hypothesis that all the independent variables in the models estimated by FMOLS and CCR are equal to zero. As seen in Table 7, the probability values of the Wald test are significant at a 5 percent significance level, suggesting that the null hypothesis is not valid. This implies that at least one of the independent variables is significantly different from zero. The results also confirm the estimated long-run impact of the variables on manufacturing output and value-added in Nigeria over the period of study.

Table 7. Normality and Wald Test Results

	FMOLS				CCR			
	Normality Test H_0: Data is normally distributed		Wald Test H_0: All $\beta = 0$		Normality Test H_0: Data is normally distributed		Wald Test H_0: All $\beta = 0$	
	Jarque-Bera Stat.	**Prob.**	**F-statistic**	**Probability**	**Jarque-Bera Stat.**	**Prob.**	**F-statistic**	**Probability**
LNMNO	0.701	0.704	11.303	0.000***	0.894	0.639	11.484	0.000***
LNMVAA	0.701	0.704	11.303	0.000***	0.894	0.639	11.484	0.000***

Source: Research finding.
Note: *** denotes significance at 1 percent level.

Long-run Estimates of the Manufacturing Sub-sectors

In this section, the study disaggregates manufacturing output into subsectors and employs FMOLS to analyze the models. Table 8 shows the effect of climate change and other explanatory variables on the manufacturing sub-sectors and the contribution of each sector to the manufacturing output. With the exception of motor vehicles and assembly (MVA), wood and wood products (WWP), and oil refining (OLR) subsectors, the results reveal that the estimated effect of climate change on the manufacturing subsectors aligns with the results of the primary model. In other words, climate change reduces the output of cement (CEM), food, beverage and tobacco (FBT), textile, apparel and footwear (TAF), pulp, paper and paper products (PPP), chemical and pharmaceutical products (CPP), non-metallic products (NMP), plastic and rubber products (PRP), electrical and electronics (EEL), and basic metal, iron, and steel (MIS) subsectors. More importantly, the study finds that the decline in the output of each subsector, especially CEM, TAF, PPP, CPP, NMP, PRP, EEL, and MIS, associated with climate change is larger than the reduction in aggregate manufacturing output. Also, the empirical evidence reveals that the textile, apparel, and footwear subsector, which contributes 13.58% to the manufacturing output, is the most vulnerable subsector to climate change in Nigeria. This is not a surprise because climate change affects cotton production and water supply, the major raw materials for the textile, apparel, and footwear subsector. Climate change events such as droughts and floods cause pests, lower soil fertility, and reduce the available water for cotton cultivation (Soviadan et al., 2019), and this affects the quantity and quality of cotton available for the textile, apparel, and footwear subsector.

Table 8. FMOLS Results of the Effect of Climate Change on the Manufacturing Sub-Sectors

Sub-sectors	C	LNLAB	LNCAP	LNCCH	LNEXC	%
LNCEM	-59.997(-1.112)	6.949***(3.854)	1.738(1.286)	-31.584**(-2.077)	-1.038***(-3.271)	5.78
LNCPP	-71.079(-1.270)	5.261***(2.811)	3.417**(2.437)	-35.810**(-2.269)	-0.374(-1.135)	0.38
LNEEL	-11.315(-0.277)	4.747***(3.479)	0.847(0.829)	-28.071**(-2.440)	-0.837***(-3.487)	0.18
LNFBT	4.902(0.293)	1.112*(1.986)	0.402(0.958)	-8.550*(-1.811)	-0.098(-0.997)	70.16
LNMIS	-63.848 (-1.369)	4.797***(3.076)	2.153*(1.843)	-23.973*(-1.823)	-0.397(-1.445)	0.85
LNMVA	3.193(0.039)	2.520(0.914)	1.054(0.510)	-22.366(-0.962)	-0.592(-1.220)	0.92
LNNMP	-44.073(-0.942)	4.166**(2.664)	2.541**(2.169)	-29.989**(-2.274)	-0.367(-1.334)	1.49
LNOLR	-591.811***(-6.856)	-3.682(-1.276)	13.900***(6.430)	75.699***(3.111)	-0.670(-1.319)	1.11
LNPPP	-27.520(-1.280)	2.174***(3.027)	1.423**(2.645)	-14.882**(-2.457)	-0.165(-1.306)	0.60
LNPRP	-81.746 (-1.256)	6.561***(3.016)	3.297*(2.023)	-38.058**(-2.075)	-0.601(-1.570)	0.70
LNTAF	-10.710(-0.246)	4.475***(3.072)	2.245*(2.056)	-38.303***(-3.118)	-0.488*(-1.902)	13.58
LNWWP	-81.733***(-4.209)	3.318***(5.112)	0.710(1.460)	2.365(0.432)	-0.302**(-2.648)	1.37

Source: Research finding.

Note: *, ** and *** denote significance at 10, 5 and 1 percent level. % is contribution of each subsector to manufacturing output over the period of study.

Table 9. CCR Results of the Effect of Climate Change on the Manufacturing Sub-Sectors

Sub-sectors	C	LNLAB	LNCAP	LNCCH	LNEXC
LNCEM	-82.205(-0.927)	6.009**(2.678)	2.973(1.419)	-36.596*(-1.952)	-0.942***(-2.924)
LNCPP	8.790(-1.207)	5.371**(2.343)	3.883*(1.776)	-36.960*(-1.954)	-0.530*(-1.768)
LNEEL	-11.086(-0.231)	5.000***(2.921)	0.738(0.475)	-28.488**(-2.683)	-0.854***(-3.604)
LNFBT	5.430(0.261)	1.130(1.622)	0.523(0.815)	-9.867*(-1.762)	-0.113(-1.176)
LNMIS	-91.141(-1.597)	4.843**(2.591)	2.779(1.604)	-21.415(-1.583)	-0.507*(-2.022)
LNMVA	42.362(0.429)	2.447(0.704)	-0.558(-0.265)	-19.537(-0.648)	-0.403(-0.889)
LNNMP	-52.109(-0.940)	4.167**(2.183)	3.173*(1.759)	-33.093**(-2.203)	-0.453*(-1.795)
LNOLR	-100.038(-1.337)	-1.986(-0.654)	-1.006(-0.796)	50.494(1.679)	0.545(1.068)
LNPPP	-25.473(-0.947)	2.252**(2.531)	1.497*(1.794)	-16.492**(-2.234)	-0.210*(-1.735)
LNPRP	-104.849(-1.385)	6.675**(2.496)	4.055(1.602)	-38.227*(-1.952)	-0.758**(-2.158)
LNTAF	-10.531(-0.206)	4.698**(2.579)	2.607(1.545)	-42.661***(-3.093)	-0.574**(-2.315)
LNWWP	-76.338***(-2.982)	3.090***(3.969)	0.573(0.761)	3.125(0.481)	-0.253***(-2.516)

Source: Research finding.

Note: *, ** and *** denote significance at 10, 5 and 1 percent level.

The next climate-vulnerable manufacturing subsector is plastic and rubber products, which account for just 0.70% of the manufacturing output. Climate change conditions like drought affect the survival of rubber plantations and also influence a larger percentage of the pests and diseases associated with rubber, which threaten plastic and rubber production (Pinizzotto et al., 2021). The chemical and pharmaceutical products subsector, accounting for just 0.38% of the manufacturing output, is the next most exposed subsector to harsh climates in Nigeria. The chemical and pharmaceutical products subsector relies on different raw materials for production, and changes in weather events affect the supply of raw materials and disrupt the distribution of the final product. Specifically, adverse weather events delay the supply of raw materials and cause instability in production (Forrest, 2023; Barrell, 2022), leading to a decline in the output of the chemical and pharmaceutical products subsector. The cement subsector, which contributes 5.78% to manufacturing output, is the next most at risk of the impact of climate change in Nigeria. Harsh weather events affect the availability and supply of raw materials such as clay, limestone, and major components, including water used for cement production, and this may lead to a decrease in cement production.

Other manufacturing subsectors exposed to harsh climates are non-metallic products, electrical and electronics, basic metal, iron, and steel, and pulp, paper, and paper products. These subsectors contribute 1.49%, 0.18%, 0.85%, and 0.60%, respectively, to manufacturing output in Nigeria. Like the other subsectors mentioned earlier, adverse weather conditions disrupt the supply chain and impact the availability and pricing of raw materials used by these subsectors. The food, beverage, and tobacco subsector, which contributes the most (70.16%) to manufacturing output in Nigeria, also suffers from climate impact. This finding lends credence to Colacito et al. (2019), who argue that hot temperatures affect households' shopping productivity and reduce the demand for food services and drinking places. It is, however, essential to note that the food, beverage, and tobacco subsector is the least affected subsector by climate change. Moreover, the study finds that Nigeria's oil refining subsector, which accounts for 1.11% of the manufacturing output, benefits from extreme weather events. This is owing to the correlation between elevated temperatures and a surge in the demand for petroleum products like gasoline, diesel, and jet fuel. This connection is a result of decreased availability of hydroelectricity (primary energy consumption source) due to water stress. Consequently, this trend may incentivize Nigeria's oil refining subsector to boost production in order to meet the heightened demand.

Furthermore, the result for motor vehicles and assembly and wood and wood products subsectors is insignificant at any conventional significance levels. Labor is significant and positively explains all the subsectors, except motor vehicles and assembly and oil refining subsectors. Similarly, capital significantly stimulates all the subsectors except cement, electrical and electronics, food, beverage and tobacco, motor vehicles and assembly, and wood and wood products subsectors. Finally, the exchange rate engenders a significant adverse effect only on cement, electrical and electronics, textile, apparel and footwear, and wood and wood products subsectors.

Robustness Checks Results

To check the robustness of the subsectors' models estimated by FMOLS, the study uses CCR to re-analyze the models and equally employs both normality and Wald restriction for diagnostic tests. The results of CCR presented in Table 9 confirm the negative effect of climate change on all the subsectors, except basic metal, iron, and steel and motor vehicles and assembly subsectors, which appear to be insignificant. Also, the empirical evidence affirms the positive effect of climate change on wood and wood products and the oil refining subsector, though it fails to explain the subsector. Moreover, there is substantial evidence that labor enhances the output of all the subsectors, except 'motor vehicles and assembly' and oil refining subsectors. Likewise, the results confirm that capital improves the output of the chemical and pharmaceutical products, non-metallic products, and pulp, paper, and paper products subsectors. In addition, the results authenticate the negative effect of the exchange rate on all the subsectors except food, beverage, and tobacco, motor vehicles and assembly, and oil refining subsectors.

Furthermore, the normality test results for FMOLS in Table 10 indicate that the series are normally distributed. Also, the Wald restriction confirmed that at least one of the independent variables is significantly different from zero for all the subsectors except for the motor vehicles and assembly subsector. Regarding the robustness test for CCR, the results confirm the normal distribution of the dataset, except for the oil refining subsector. In addition, the Wald restriction test affirms the estimated long-run impact of the variables on manufacturing subsectors.

Table 10. Normality and Wald Test Results

	FMOLS				CCR			
	Normality Test H_0: Data is normally distributed		Wald Test H_0: All $\beta = 0$		Normality Test H_0: Data is normally distributed		Wald Test H_0: All $\beta = 0$	
	Jarque-Bera Stat.	Prob.	F-statistic	Probability	Jarque-Bera Stat.	Prob.	F-statistic	Probability
LNCEM	1.687	0.430	8.992	0.000***	2.255	0.324	11.948	0.000***
LNCPP	2.018	0.365	17.665	0.000***	1.304	0.521	17.018	0.000***
LNEEL	0.701	0.704	5.503	0.002***	0.598	0.742	6.470	0.000***
LNFBT	4.356	0.113	4.649	0.006***	1.823	0.402	4.711	0.005***
LNMIS	1.460	0.482	15.923	0.000***	1.641	0.440	16.277	0.000***
LNMVA	1.469	0.480	0.784	0.546	1.253	0.535	127.093	0.000***
LNNMP	1.622	0.444	12.704	0.000***	0.996	0.608	12.999	0.000***
LNOLR	1.330	0.514	17.358	0.000***	17.556	0.000***	12.130	0.000***
LNPPP	1.435	0.488	19.746	0.000***	0.943	0.624	20.394	0.000***
LNPRP	2.151	0.341	14.500	0.000***	1.573	0.455	14.064	0.000***
LNTAF	0.500	0.780	11.156	0.000***	0.782	9.676	10.575	0.000***
LNWWP	1.452	0.484	45.222	0.000***	1.242	0.537	47.300	0.000***

Source: Research finding.

Note: *** denotes significance at 1 percent level.

Conclusion

This paper investigates the long-run effect of climate change on manufacturing sector heterogeneity in Nigeria from 1990 to 2021. To achieve this objective, the study uses fully modified ordinary least squares (FMOLS) to estimate the models and checks the robustness of the models with canonical cointegrating regression (CCR), normality test, and Wald restriction test. The empirical findings reveal that climate change has a significant negative effect on manufacturing sector output and value-added in Nigeria. The results further show that the adverse impact of climate change on the Nigerian manufacturing sector cannot be attributed only to the damaging effect of extreme weather events on a few manufacturing subsectors but rather on a large number of manufacturing subsectors, accounting for over 90% of the manufacturing output in Nigeria. Like other developing countries, the Nigerian manufacturing sector still suffers from the impact of climate change. A significant number of the manufacturing subsectors rely on the raw materials from the agricultural industry, but climate change events such as droughts and floods, as well as pests, affect the survival of rubber, used for the manufacturing of plastic and rubber products, and cotton, which is used for the manufacturing of textile, apparel, and footwear. Also, climate change lowers soil fertility and resources, including water used to cultivate cotton and rubber, among others. This affects the quantity and quality of raw materials available for manufacturing production and hence causes output shortage. Moreover, rising climatic conditions disrupt the manufacturing sector's supply chain. Floods or droughts delay the delivery of raw materials, distort the production schedule, and affect the manufacturing sector's finished goods distribution. In addition to the increase in production costs, these can cause a shortfall in the manufacturing sector output.

Regarding the response of aggregate manufacturing and subsectors' output to labor and capital, the results strongly support the neoclassical growth theoretical prediction of positive relationships. This suggests that efforts to boost aggregate manufacturing and subsectors’ output levels in Nigeria require increased capital and labor. Additionally, the exchange rate has a negative impact on the aggregate manufacturing and subsectors' output. This result explains the worries of Nigerian manufacturers regarding exchange rate depreciation and also signals the need to declare a state of emergency in the Nigerian manufacturing sector. Currently, imported materials constitute the greater percentage of Nigeria's manufacturing sector input, and the continuous decline in the value of the Nigerian currency will continue to exacerbate production costs. This will make locally manufactured products more expensive than imported goods. The study conducts robustness tests to ensure the empirical findings are reliable for policy formulation and the results are consistent with the basic model.

The empirical findings reveal that climate change and exchange rates have heterogeneous effects on the Nigerian manufacturing subsectors. Therefore, the government must make substantial efforts to address climate and exchange rate issues and account for these variables' heterogeneous effects on the manufacturing subsectors. The government must prioritize the development and implementation of all-inclusive climate change mitigation and adaptation policies with a view to addressing the vulnerabilities of key manufacturing subsectors. Furthermore, the government should recognize the vulnerabilities of raw material supply chains to climate-related events and implement policies that enhance climate resilience in the manufacturing sector. These are measures that promote sustainable agricultural practices that address the shocks of droughts and floods on manufacturing inputs like rubber and cotton. In addition, the government should discourage the consumption of fossil fuels and actively encourage the adoption of renewable energy sources such as solar, wind, hydro, and geothermal. Mass production and usage of energy-efficient technologies should also be encouraged to reduce greenhouse gas emissions. The need to curb inflation and improve the exchange rate cannot be overemphasized. This will assist in reducing reliance on imported materials and escalating production costs. In the same vein, structural reforms should be implemented to promote local production and reduce dependence on imported final goods. The government should create an enabling environment for local industries by enhancing export capacity and providing incentives for the manufacturing sector's production.

Appendix

Table I. Summary Statistics of the Dependent and Independent Variables

	Mean	Maximum	Minimum	Standard Deviation	Observation
Manufacturing output (MNO)	4290.255	6684.218	2898.474	1407.532	32
Manufacturing value added (MVAA)	$4.29*10^{+12}$	$6.68*10^{+12}$	$2.90*10^{+12}$	$1.41*10^{+12}$	32
Cement subsector (CEM)	286.0222	658.6147	87.12829	186.2611	32
Chemical and pharmaceutical products subsector (CPP)	58.97911	172.3777	14.60659	57.52421	32
Electrical and electronics subsector (EEL)	3.676657	6.719975	1.800953	1.559104	32
Food, beverage and tobacco subsector (FBT)	2481.341	3220.079	1893.217	409.7477	32
Basic metal, iron, and steel subsector (MIS)	75.96238	169.6850	28.82857	58.88222	32
Motor vehicles and assembly subsector (MVA)	12.73326	20.92708	6.552817	4.521102	32
Non-metallic product subsector (NMP)	105.3707	241.9533	54.49521	74.20003	32
Oil refining subsector (OLR)	135.3706	344.7107	19.29784	92.15830	32
Pulp, paper and paper products subsector (PPP)	31.32928	53.92540	21.66373	12.47618	32
Plastic and rubber products subsector (PRP)	82.60640	231.9425	25.06864	83.42670	32
Textile, apparel and footwear subsector (TAF)	720.9408	1443.030	344.0592	433.4226	32
Wood and wood products subsector (WWP)	111.1590	205.2262	49.16998	60.97046	32
Labor (LAB)	48746706	70620043	31936585	11147705	32
Capital (CAP)	$8.68*10^{+12}$	$1.14*10^{+12}$	$6.86*10^{+12}$	$1.25*10^{+12}$	32
Climate change (CCH)	27.31063	27.86000	26.59000	0.294979	32
Exchange rate (EXC)	137.8190	401.1520	8.038285	106.9853	32

Source: Research finding.

Table II. VAR Lag Order Selection Criteria

Lag	LogL	LR	FPE	AIC	SC	HQ	LogL	LR	FPE	AIC	SC	HQ
			LNCEM						LNCPP			
0	116.7096	NA	$3.10*10^{-10}$	-7.704111	-7.468370	-7.630280	113.5460	NA	$3.86*10^{-10}$	-7.485930	-7.250190	-7.412099
1	244.0374	201.9682	$2.75*10^{-13}$	-14.76120	-13.34675	-14.31821	252.8459	220.9584	$1.50*10^{-13}$	-15.36868	-13.95424*	-14.92569
2	290.0404	57.10725*	$7.66*10^{-14}$	-16.20968	-13.61654*	-15.39754	293.3836	50.32276*	$6.09*10^{-14*}$	-16.44025	-13.84710	-15.62811*
3	323.0579	29.60191	$7.21*10^{-14*}$	-16.76262*	-12.99077	-15.58132*	319.6833	23.57899	$9.10*10^{-14}$	-16.52988*	-12.75803	-15.34859
			LNEEL						LNFBT			
0	123.1414	NA	$1.99*10^{-10}$	-8.147686	-7.911945	-8.073855	153.8891	NA	$2.39*10^{-11}$	-10.26821	-10.03247	-10.19438
1	247.5769	197.3803	$2.16*10^{-13}$	-15.00530	-13.59086*	-14.56232	268.1720	181.2763*	$5.21*10^{-14}$	-16.42565	-15.01121*	-15.98267*
2	279.9992	40.24843*	$1.53*10^{-13}$	-15.51719	-12.92404	-14.70505	297.0943	35.90357	$4.71*10^{-14}$	-16.69616*	-14.10301	-15.88402
3	310.4040	27.25944	$1.73*10^{-13}$	-15.88993*	-12.11808	-14.70863*	317.4567	18.25597	$1.06*10^{-13}$	-16.37633	-12.60448	-15.19503
			LNMIS						LNMVA			
0	118.6599	NA	$2.71*10^{-10}$	-7.838611	-7.602870	-7.764780	129.9246	NA	$1.25*10^{-10}$	-8.615489	-8.379748	-8.541658
1	246.3192	202.4942	$2.35*10^{-13}$	-14.91857	-13.50412*	-14.47558	265.4876	215.0310	$6.28*10^{-14}$	-16.24052	-14.82608*	-15.79754
2	286.5158	49.89914*	$9.77*10^{-14}$	-15.96660	-13.37346	-15.15446	301.8940	45.19415*	$3.38*10^{-14*}$	-17.02717	-14.43402	-16.21503*
3	318.8820	29.01805	$9.62*10^{-14*}$	-16.47462*	-12.70277	-15.29333*	328.5991	23.94250	$4.92*10^{-14}$	-17.14476*	-13.37291	-15.96347
			LNNMP						LNOLR			
0	121.4284	NA	$2.24*10^{-10}$	-8.029545	-7.793805	-7.955714	97.52131	NA	$1.17*10^{-09}$	-6.380780	-6.145039	-6.306949
1	253.9162	210.1531	$1.39*10^{-13}$	-15.44250	-14.02805*	-14.99951	225.5979	203.1559*	$9.83*10^{-13}$	-13.48951	-12.07506*	-13.04652
2	293.1254	48.67344	$6.20*10^{-14}$	-16.42244	-13.82929	-15.61030	253.3121	34.40393	$9.65*10^{-13}$	-13.67670	-11.08355	-12.86456
3	337.4173	39.70997*	$2.68*10^{-14*}$	-17.75291*	-13.98106	-16.57162*	290.6827	33.50468	$6.72*10^{-13*}$	-14.52984*	-10.75799	-13.34855*
			LNPPP						LNPRP			
0	136.8742	NA	$7.72*10^{-11}$	-9.094770	-8.859030	-9.020939	112.1111	NA	$4.26*10^{-10}$	-7.386975	-7.151234	-7.313144
1	271.8741	214.1378	$4.04*10^{-14}$	-16.68097	-15.26653*	-16.23799	243.8563	208.9752	$2.79*10^{-13}$	-14.74871	-13.33427*	-14.30573
2	311.5661	49.27280*	$1.74*10^{-14}$	-17.69421	-15.10106	-16.88207*	283.3169	48.98555*	$1.22*10^{-13}$	-15.74599	-13.15285	-14.93385
3	341.8209	27.12504	$1.98*10^{-14}$	-18.05662*	-14.28476	-16.87532	315.6284	28.96889	$1.20*10^{-13*}$	-16.25023*	-12.47838	-15.06894*
			LNTAF						LNWWP			
0	118.2486	NA	$2.79*10^{-10}$	-7.810250	-7.574509	-7.736419	136.2048	NA	$8.09*10^{-11}$	-9.048607	-8.812867	-8.974776
1	252.6348	213.1643	$1.52*10^{-13}$	-15.35413	-13.93968*	-14.91114	256.2020	190.3403	$1.19*10^{-13}$	-15.60014	-14.18569*	-15.15715
2	288.1279	44.06031*	$8.74*10^{-14*}$	-16.07778	-13.48464	-15.26564*	287.6868	39.08462*	$9.01*10^{-14*}$	-16.04737*	-13.45422	-15.23522*
3	313.5434	22.78635	$1.39*10^{-13}$	-16.10644*	-12.33459	-14.92515	309.6639	19.70361	$1.82*10^{-13}$	-15.83889	-12.06704	-14.65759

Source: Research finding.

Table III. Johansen Cointegration Test Results

H_0	r = 0	r ≤ 1	r ≤ 2	r ≤ 3	r ≤ 4	r = 0	r ≤ 1	r ≤ 2	r ≤ 3	r ≤ 4
	LNCEM					LNCPP				
Eigenvalue	0.670	0.572	0.358	0.309	0.026	0.849	0.527	0.386	0.195	0.095
Trace Stat	81.039**	48.923**	24.307	11.471	0.761	103.227**	46.578	24.132	9.518	3.010
Max-Eig. Stat	32.116	24.616	12.836	10.710	0.761	56.649**	22.446	14.614	6.508	3.010
	LNEEL					LNFBT				
Eigenvalue	0.838	0.568	0.395	0.216	0.015	0.793	0.496	0.325	0.232	0.011
Trace Stat	102.529**	47.975**	22.813	7.748	0.447	87.878**	40.567	20.018	8.244	0.324
Max-Eig. Stat	54.553**	25.162	15.065	7.301	0.447	47.310**	20.549	11.774	7.920	0.324
	LNMIS					LNMVA				
Eigenvalue	0.837**	0.616	0.290	0.192	0.035	0.842	0.787	0.365	0.134	0.023
Trace Stat	100.798**	46.432	17.754	7.480	1.070	120.427**	65.073**	18.640	5.025	0.694
Max-Eig. Stat	0.837**	0.616**	0.290	0.192	0.035	55.354**	46.432**	13.615	4.331	0.694
	LNNMP					LNOLR				
Eigenvalue	0.865	0.583	0.287	0.187	0.040	0.828	0.519	0.490	0.168	0.001
Trace Stat	103.765**	43.775	17.567	7.431	1.233	100.562**	47.723	25.758	5.540	0.037
Max-Eig. Stat	59.990**	26.207	10.136	6.198	1.233	52.839**	21.964	20.218	5.503	0.037
	LNPPP					LNPRP				
Eigenvalue	0.857	0.602	0.238	0.201	0.063	0.851	0.586	0.318	0.192	0.056
Trace Stat	102.787**	44.515	16.857	8.688	1.958	103.116**	46.034	19.607	8.138	1.741
Max-Eig. Stat	58.273**	27.658**	8.169	6.729	1.958	57.082**	26.427	11.470	6.396	1.741
	LNTAF					LNWWP				
Eigenvalue	0.843	0.508	0.381	0.252	0.064	0.823	0.507	0.366	0.255	0.015
Trace Stat	101.868**	46.32	25.059	10.684	1.971	96.237**	44.216	22.981	9.313	0.466
Max-Eig. Stat	55.548**	21.261	14.375	8.712	1.971	52.021**	21.235	13.668	8.847	0.466

Source: Research finding.

Statements and Declarations
- Funding: This work does not receive any funding.
- Conflict of interest: The authors declare that there is no conflict of interest.

References

AfDB. (2019). Climate Change in Africa. Publication of the African Development Bank Group. Retrieved from https://www.afdb.org/en/cop25/climate-change-africa.

Akinbode, S. O., Fapetu, O., Olabisi, J., & Ojo, O. T. (2019). Impact of Exchange Rate on Economic Growth in Nigeria (1981-2016): An ARDL Approach. *Contemporary Economy Journal, 4*(2), 158-171. Retrieved from http://www.revec.ro/papers/190220.pdf.

Akpan, E. O., & Atan, J. A. (2011). Effects of Exchange Rate Movements on Economic Growth in Nigeria. *CBN Journal of Applied Statistics, 2*(2), 1-14. Retrieved from https://www.econstor.eu/bitstream/10419/142047/1/cbn-jas_v2-i2-pp001-014.pdf.

Akram, N. (2013). Is Climate Change Hindering Economic Growth of Asian Economies. *Asia-Pacific Development Journal, 19*(2), 1-18. Retrieved from https://www.academia.edu/download/70043161/Is_climate_change_hindering_economic_gro20210921-25112-191v1x1.pdf.

Anh, D. L. T., Anh, N. T., & Chandio, A. A. (2023). Climate Change and its Impacts on Vietnam Agriculture: A Macroeconomic Perspective. *Ecological Informatics, 74,* 101960. Retrieved from https://www.sciencedirect.com/science/article/pii/S1574954122004101.

Aryeetey, E., & Baffour, P. T. (2022). African Competitiveness and the Business Environment: Does Manufacturing Still Have a Role to Play? *Journal of African Economies, 31*(Supplement_1), i33–i58. Retrieved from https://academic.oup.com/jae/article-pdf/31/Supplement_1/i33/45739711/ejac019.pdf.

Awolaja, A. G., & Okedina, I. M. (2020). Investigating the Asymmetric Effect of Exchange Rate on Agricultural Output in Nigeria, 1981-2017. *Economic and Financial review, 58*(4), 41-62. Retrieved from https://www.researchgate.net/.

Baarsch, F., & Schaeffer, M. (2019). Climate Change Impacts on Africa's Economic Growth. Africa Development Bank, Abidjan. Retrieved from https://www.afdb.org/sites/default/files/documents/publications/afdb-economics_of_climate_change_in_africa.pdf.

Barrell, A. (2022). Pharma's Climate Change Vulnerability and Opportunity. Retrieved from https://pharmaphorum.com/views-and-analysis/pharmas-climate-change-vulnerability-and-opportunity.

Benjamin, O. O., Akinola, G. W., & Adeoba, A. A. (2023). Fossil Energy Consumption, Carbon Dioxide Emissions and Adult Mortality Rate in Nigeria. *Managing Global Transitions 21*(4), 251–282. Retrieved from https://ojs.upr.si/index.php/fm/article/view/151/56.

Birnintsaba, D. A. B., Ozdeser, H., & Saliminezhad, A. (2021). Impact Analysis on the Effective Synergy between Climate Change, Ecological Degradation and Energy Consumption on Economic Growth in Nigeria. *SAGE Open, 11*(4), Retrieved from https://journals.sagepub.com/doi/pdf/10.1177/21582440211061361.

Cai, X., Lu, Y. & Wang, J. (2018). The Impact of Temperature on Manufacturing Worker Productivity: Evidence from Personnel Data. *Journal of Comparative Economics, 46*(4), 889-905. Retrieved from https://www.sciencedirect.com/science/article/pii/S014759671830204X .

Cavanaugh, J. E., & Neath, A. A. (1999). Generalizing the Derivation of the Schwarz Information Criterion. *Communications in Statistics-Theory and Methods, 28*(1), 49-66. Retrieved from https://www.stat.unm.edu/~ronald/courses/Int_Bayes/Cav_BIC.pdf.

Chen, J., Fonseca, M. A., Heyes, A., Yang, J., & Zhang, X. (2023). How much will Climate Change Reduce Productivity in a High-technology Supply Chain? Evidence from Silicon Wafer Manufacturing. *Environmental and Resource Economics, 86,* 533–563. Retrieved from https://pmc.ncbi.nlm.nih.gov/articles/PMC10581999/pdf/10640_2023_Article_803.pdf.

Chen, K., Wang, G., Chen, J., Yuan, S., & Wei, G. (2020). Impact of Climate Changes on Manufacturing: Hodrick-Prescott Filtering and a Partial Least Squares Regression Model. *International Journal of Computational Science and Engineering, 22*(2-3), 211-220. Retrieved from https://www.inderscienceonline.com/doi/abs/10.1504/IJCSE.2020.107343.

Chen, X., & Yang, L. (2019). Temperature and Industrial Output: Firm-level Evidence from China. *Journal of Environmental Economics and Management, 95,* 257-274. Retrieved from https://www.sciencedirect.com/science/article/pii/S009506961730520X.

Cho, R. (2019). How Climate Change Impact the Economy. Columbia Climate School Publication. Retrieved from https://news.climate.columbia.edu/2019/06/20/climate-change-economy-impacts/.

Colacito, R., Hoffmann, B., & Phan, T. (2019). Temperature and Growth: A Panel Analysis of the United States. *Journal of Money, Credit and Banking, 51*(2-3), 313-368. Retrieved from https://onlinelibrary.wiley.com/doi/pdfdirect/10.1111/jmcb.12574.

Dasgupta, S., van Maanen, N., Gosling, S. N., Piontek, F., Otto, C., & Schleussner, C. F. (2021). Effects of Climate Change on Combined Labour Productivity and Supply:

An Empirical, Multi-model Study. *The Lancet Planetary Health, 5*(7), e455-e465. Retrieved from https://www.thelancet.com/pdfs/journals/lanplh/PIIS2542-5196(21)00170-4.pdf.

Dickey, D. A., & Fuller, W. A. (1979). Distribution of the Estimators for Autoregressive Time Series with a Unit Root. *Journal of the American Statistical Association, 74*(366a), 427-431. Retrieved from https://www.academia.edu/download/43130770/Distribution_of_the_Estimators_For_Autor20160227-13006-8ub51z.pdf.

Farajzadeh, Z., Ghorbanian, E., & Tarazkar, M. H. (2023). The Impact of Climate Change on Economic Growth: Evidence from a Panel of Asian Countries. *Environmental Development, 47,* 100898. Retrieved from https://www.sciencedirect.com/science/article/pii/S2211464523000982.

Farouq, I. S., & Sambo, N. U. (2022). Real Exchange Rate and Economic Growth: The Interacting Role of Financial Development in Nigeria. *Iranian Economic Review, 26*(4), 905-921. Retrieved from https://ier.ut.ac.ir/article_90664_5a9b3bd762561157d7ac2bcfc3cf94e3.pdf.

Fatusin, A. F., Fagbohunka, A., & Yoade, A. O. (2019). The Impact of Climate Change on Growth and Development of Agro-Allied Small-Scale Industries in Nigeria. *Ghana Journal of Geography, 11*(1), 87-102.

Forrest, F. (2023). The Impact of Climate Change on the Pharma Supply Chain. Retrieved from https://www.pharmaceutical-technology.com/sponsored/the-impact-of-climate-change-on-the-pharma-supply-chain/.

Foye, V. O., & Benjamin, O. O. (2021). Climate Change, Technology and Manufacturing Sector Growth in Oil-rich Nigeria. *International Journal of Sustainable Economy, 13*(3), 236-260. Retrieved from https://www.inderscienceonline.com/doi/abs/10.1504/IJSE.2021.116643.

Foye, V. O. (2022). Climate Change and Macro Prices in Nigeria: A Nonlinear Analysis. *Managing Global Transitions, 20*(2). Retrieved from https://ojs.upr.si/index.php/fm/article/view/77/26.

---------- (2020). Impacts of Population and Climate Change on Sustainable Development in Nigeria.

---------- (2018). Dynamics of Climate Change, Human Health and Economic Growth: Evidence from Nigeria. *African Journal of Sustainable Development 8*(2), 31-61. Retrieved from https://africajsd.com/wp-content/uploads/2025/07/3-Dynamics-of-Climate-Change-AJSD-for-Review_Correction_Updated.pdf.

Hernandez, K., & Madeira, C. (2022). The Impact of Climate Change on Economic Output Across Industries in Chile. *PLoS ONE, 17*(4), e0266811. Retrieved from https://journals.plos.org/plosone/article/file?id=10.1371/journal.pone.0266811&type=printable.

Hoang, H. H., & Huynh, C. M. (2021). Climate Change, Economic Growth and Growth Determinants: Insights from Vietnam's Coastal South-Central Region. *Journal of Asian and African Studies, 56*(3), 693-704. Retrieved from https://journals.sagepub.com/doi/pdf/10.1177/0021909620940345.

Huang, K., Zhao, H., Huang, J., Wang, J., & Findlay, C. (2020). The Impact of Climate Change on the Labor Allocation: Empirical Evidence from China. *Journal of Environmental Economics and Management, 104,* 102376. Retrieved from https://www.sciencedirect.com/science/article/pii/S0095069620300991.

IPCC. (2023). Summary for Policymakers. In: Climate Change 2023: Synthesis Report. Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. In H. Lee and J. Romero (Eds.). *IPCC* (1-34), Geneva.

Jakada, A. H., & Mahmood, S. (2023). An Application of Quantile Regression on the Relationship between Economic Growth and the Quality of Environment in Selected African Countries. *Iranian Economic Review, 27*(2), 283-315. Retrieved from https://ier.ut.ac.ir/article_94026_f3496bca8fc4b3e7722313a7d39625dd.pdf.

Johansen, S. (1991). Estimation and Hypothesis Testing of Cointegration Vectors in Gaussian Vector Autoregressive Models. *Econometrica: journal of the Econometric Society,* 1551-1580. Retrieved from https://www.jstor.org/stable/2938278.

---------- (1988). Statistical Analysis of Cointegration Vectors. *Journal of economic dynamics and control, 12*(2-3), 231-254. Retrieved from https://www.sciencedirect.com/science/article/pii/0165188988900413.

Kabore, P., & Rivers, N. (2023). Manufacturing output and extreme temperature: Evidence from Canada. *Canadian Journal of Economics, 56*(1), 191-224. Retrieved from https://institute.smartprosperity.ca/sites/default/files/WP_manufacturing%20Output.pdf.

Kadanali, E., & Yalcinkaya, O. (2020). Effects of Climate Change on Economic Growth: Evidence from 20 Biggest Economies of the World. *Romanian Journal of Economic Forecasting, 23*(3), 93. Retrieved from https://ipe.ro/rjef/rjef3_20/rjef3_2020p93-118.pdf.

Kahn, M. E., Mohaddes, K., Ng, R. N., Pesaran, M. H., Raissi, M., & Yang, J. C. (2021). Long-Term Macroeconomic Effects of Climate Change: A Cross-Country Analysis. *Energy Economics, 104,* 105624. Retrieved from https://www.sciencedirect.com/science/article/pii/S0140988321004898.

Kalaitzi, A. S., & Chamberlain, T. W. (2020). Exports and Economic Growth: Some Evidence from the GCC. *International Advances in Economic Research, 26*(2), 203-205. Retrieved from https://link.springer.com/content/pdf/10.1007/s11294-020-09786-0.pdf.

Kalkuhl, M., & Wenz, L. (2020). The Impact of Climate Conditions on Economic Production. Evidence from a Global Panel of Regions. *Journal of Environmental Economics and Management*, Retrieved from https://doi.org/10.1016/j.jeem.2020.102360.

Kandil, M., & Mirzaie, I. (2005). The Effects of Exchange Rate Fluctuations on Output and Prices: Evidence from Developing Countries. *The Journal of Developing Areas, 38*(5), 189-219. Retrieved from https://link.springer.com/content/pdf/10.1007/s11294-020-09786-0.pdf.

Kheifets, I. L., & Phillips, P. C. (2023). Fully Modified Least Squares Cointegrating Parameter Estimation in Multicointegrated Systems. *Journal of Econometrics, 232*(2), 300-319. Retrieved from https://www.sciencedirect.com/science/article/pii/S030440762100186X.

Khurshid, N., Fiaz., A., Khurshid, J., & Ali, K. (2022). Impact of Climate Change Shocks on Economic Growth: A New Insight from Non-Linear Analysis. *Frontiers in Environmental Science, 10*, 1039128. Retrieved from https://www.frontiersin.org/journals/environmental-science/articles/10.3389/fenvs.2022.1039128/full.

Murphy, D., & Harris, M. (2014). Climate Change and the Energy and Manufacturing Sector. Retrieved from https://cdkn.org/sites/default/files/files/Climate-Change-and-the-Energy-Sector.pdf.

Naseem, S., Hu, X., & Mohsin, M. (2023). Elongating the Role of Renewable Energy and Sustainable Foreign Direct Investment on Environmental Degradation. *Heliyon, 9,* e18421. Retrieved from https://www.cell.com/heliyon/pdf/S2405-8440(23)05629-3.pdf.

Nasreen, S., Anwar, S., & Ozturk, I. (2017). Financial Stability, Energy Consumption and Environmental Quality: Evidence from South Asian Economies. *Renewable and Sustainable Energy Reviews, 67,* 1105-1122. Retrieved from https://www.sciencedirect.com/science/article/pii/S1364032116305147.

Neath, A. A., & Cavanaugh, J. E. (1997). Regression and Time Series Model Selection using Variants of the Schwarz Information Criterion. *Communications in Statistics-Theory and Methods, 26*(3), 559-580. Retrieved from https://www.tandfonline.com/doi/abs/10.1080/03610929708831934.

Ogbuabor, J. E. & Egwuchukwu, E. I. (2017). The Impact of Climate Change on the Nigerian Economy. *International Journal of Energy Economics and Policy, 7*(2), 217-223. Retrieved from https://dergipark.org.tr/en/download/article-file/361739 .

Olaifa, F. G., & Benjamin, O. O. (2020). Government Capital Expenditure and Private Sector Investment in Nigeria: Co-integration Regression and Toda-Yamamoto Causality Analysis. *Advanced Journal of Social Science*, *6*(1), 71-82. Retrieved from https://journals.aijr.org/index.php/ajss/article/download/1539/232.

Osabohien, R., Akinpelumi, D., Matthew, O., Okafor, V., Iku, E., Olawande, T., & Okorie, U. (2019). Agricultural Exports and Economic Growth in Nigeria: An Econometric Analysis. *IOP Conference Series: Earth and Environmental Science, 331,* 012002. Retrieved from https://iopscience.iop.org/article/10.1088/1755-1315/331/1/012002/pdf.

Pedroni, P. (2001). Fully Modified OLS for Heterogeneous Cointegrated Panels. Retrieved from https://www.emerald.com/books/edited-volume/12403/chapter-abstract/82571972.

Perman, R. (1991). Cointegration: An Introduction to the Literature. *Journal of Economic Studies, 18(3),* 3-30. Retrieved from https://www.emerald.com/jes/article/doi/10.1108/EUM0000000000151/220766.

Phillips, P. C. & Hansen, B. E. (1990). Statistical Inference in Instrumental Variables Regression with I(1) Processes. *The Review of Economic Studies, 57*(1), 99-125. Retrieved from https://elischolar.library.yale.edu/cgi/viewcontent.cgi?article=2111&context=cowles-discussion-paper-series.

Phillips, P. C. & Perron, P. (1988). Testing for a Unit Root in Time Series Regression. *Biometrika, 75*(2), 335-346. Retrieved from https://elischolar.library.yale.edu/cgi/viewcontent.cgi?article=2037&context=cowles-discussion-paper-series.

Pinizzotto, S., Kadir, A. A. S. A., Gitz, V., Sainte-Beuve, J., Nair, L., Gohet, E., Penot, E., & Meybeck, A. (2021). Natural Rubber and Climate Change: A Policy Paper, 6. Retrieved from https://www.rubberstudy.org/storage/uploads/contentfile/22192/fl52Il6p1b.pdf.

Sequeira, T. N., Santos, M. S., & Magalhães, M. (2018). Climate Change and Economic Growth: A Heterogeneous Panel Data Approach. *Environmental Science and Pollution Research, 25,* 22725-22735. Retrieved from https://link.springer.com/content/pdf/10.1007/s11356-018-2305-7.pdf.

Somanathan, E., Somanathan, R., Sudarshan, A., & Tewari, M. (2021). The Impact of Temperature on Productivity and Labor Supply: Evidence from Indian Manufacturing. *Journal of Political Economy, 129(6),* 1797-1827. Retrieved from https://www.journals.uchicago.edu/doi/pdf/10.1086%2F713733.

Soviadan, M., Koffi-Tessio, E., Enete, A., & Nweze, N. (2019). Impact of Climate Change on Cotton Production: Case of Savannah Region, Northern Togo. *Agricultural Sciences, 10,* 927-947. Retrieved from https://hal.science/hal-03093117/document.

Tajudeen, T. T., Omotayo, A., Ogundele, F. O., & Rathbun, L. C. (2022). The Effect of Climate Change on Food Crop Production in Lagos State. *Foods, 11*(24), 3987. Retrieved from https://www.mdpi.com/2304-8158/11/24/3987.

U.S. Department of State (2015). Nigeria Investment Climate Statement 2015. Retrieved from https://2009-2017.state.gov/documents/organization/241898.pdf.

Uruakpa, G. C., Okorontah, C. F., & Ede, L. O. (2021). Exchange Rate and the Performance of Manufacturing Firms in Nigeria. *International Journal of Business and Social Science, 7*(1), 12-19. Retrieved from https://rujmass.com/Journals/2021/011.pdf.

USAID. (2019). Climate Risk Profile: Nigeria. Retrieved from https://www.climatelinks.org/resources/climate-risk-profile-nigeria.

Van Huong, N., Minh Nguyet, B. T., Van Hung, H., Minh Duc, H., Van Chuong, N., Do Tri, M., Van Hien, D., & Van Hien, P. (2022). Economic Impact of Climate Change on Agriculture: A Case of Vietnam. *Agbioforum, 24*(1), 1-12. Retrieved from https://agbioforum.org/menuscript/index.php/agb/article/download/72/50/.

Wolf, C. (2023). Demand-Growth in Support of Structural Change: Evidence from Nigeria's Formal Manufacturing Sector. *Structural Change and Economic Dynamics, 67,* 347-358. Retrieved from https://www.sciencedirect.com/science/article/pii/S0954349X23001182.

World Bank. (2021). Climate Risk Country Profile: Nigeria. Washington, DC: World Bank Publications.

World Bank, 2023. World Development Indicators. Retrieved from https://data.worldbank.org/indicator/GB.XPD.RSDV.GD.ZS?locations=NG.

Zhang, P., Deschenes, O., Meng, K., Zhang, J. (2018). Temperature Effects on Productivity and Factor Reallocation: Evidence from A Half-Million Chinese Manufacturing Plants. *Journal of Environmental Economics and Management, 88*, 1-17. Retrieved from https://www.sciencedirect.com/science/article/pii/S0095069617304588.

Zhu, W., Ahmad, F., Draz, M. U., Ozturk, I., Rehman, A. (2022). Revisiting the Nexus between Exchange Rate, Exports and Economic Growth: Further Evidence from Asia. *Economic Research, 35*(1), 7128-7146. Retrieved from https://hrcak.srce.hr/file/436946.

Cite this article: Benjamin, O. O., & Foye, V. O. (2026). Heterogeneous Effects of Climate Change on Output across the Manufacturing Subsectors in Nigeria. *Iranian Economic Review, 30*(2), 540-574.