“Is climate change a source of economic disparities between regions in Benin? Evidence from the spatial effects analysis method”

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IS CLIMATE CHANGE A SOURCE OF ECONOMIC DISPARITIES BETWEEN REGIONS IN BENIN? EVIDENCE FROM THE SPATIAL EFFECTS ANALYSIS METHOD

Abstract

Despite numerous studies on the impacts of climate change in developing economies, scarce research focuses on these spatial effects in the internal regions of these countries. To shed light on this concern, this study aims to analyze the spatial effect of climate change on regional economic disparities in the context of Benin. The secondary data are extracted from the World Bank's Climate Knowledge Portal and a Beninese local finance database covering the period from 2010 to 2019. A random-effects panel model and a dynamic spatial Durbin model of endogenous growth are used. The results reveal that, in the absence of spatial effects, average temperature reinforces economic disparities by 4.4 points within regions. A one-point increase in precipitation increases economic disparities by 0.001 points. The spatial model reveals both short- and long-term positive spatial externalities. Thus, a one-point positive variation in precipitation in neighboring regions leads to a 0.005% increase in a given region's own revenue per capita. Similarly, a one-point increase in precipitation in a given region induces a 0.004% rise in own revenues in neighboring regions. Damage caused by climate change in one area encourages positive economic dynamics in neighboring areas. These spatial interactions reinforce economic differences and maintain economic disparities between Benin's regions.

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INTRODUCTION

Climate change has a negative impact on the economies of developing countries. It has a multi-sectoral effect that results in huge losses of income. This maintains economic disparities between and within countries (Warsame et al., 2021; Ahsan et al., 2020). For a long time, research into the economic disparities caused by climate change has focused on the effects between countries, ignoring those between regions within the same country. Yet these effects are not only present but more severe between regions of the same country (Anyanwu et al., 2016). Regions receive the effects of climate change differently because their level of vulnerability is not the same. Some regions are more affected due to the fragility of their resources or the fact that their economic activities are directly dependent on the climate.

The downside of this situation is a lasting drop in income, mainly in the least developed regions, leading to increased regional economic disparities within countries. What is more, regions that share borders with others develop close relationships that influence their respective economies. There is a spatial economic dynamic maintained between them. In this context, the effect of climate change, whether positive or negative, must also be explained by a spatial dynamic that cannot be overlooked. Faced with the serious consequences of climate change, it is essential to capture the spatial externalities of climate change that maintain economic disparities in the search for appropriate policies.

1. LITERATURE REVIEW

Numerous studies have examined the consequences of climate change and its impact on regional economic performance. Manifestations of climate change strongly reduce economic performance and significantly determine economic disparities between regions (Benhamed et al., 2023; Dehn & Collier, 2001; He et al., 2021). The debate on regional disparities has given rise to two schools of thought.

The first is based on neoclassical economic theory and advocates convergence, and the second is based on cumulative causality theory that defends the divergence of disparities (Oţil et al., 2015). For neoclassical theory, increased regional production results from increased mobility of production factors and technologies. Thus, the reduction of regional disparities can be achieved in the long term by following the process of regional convergence under the effect of per capita income growth. In contrast, traditional disparity theories assume that economic disparities between regions stem from the differentiated endowment of natural resources, factors of production, infrastructure, and technology (Bălan et al., 2020). Opposing ideas have developed that performance, perceived as a cumulative spatial process, is responsible for economic disparities. Other factors of disparity have also been put forward, notably innovation capacity, human capital, and geographical factors (Ostermeyer, 2023).

Capello (2009) and Torre (2015) have highlighted environmental issues (climate change) (Torre & Chia, 2017) as factors in disparities. Climate change thus appears to be a predominant factor affecting the economies of regions within countries (Yang & Tang, 2022). The channels through which climate change affects the economy are established by analyzing factors such as the importance of climate-sensitive sectors (agriculture, tourism, etc.) in the economy and their repercussions on factor allocation (Hallegatte & Rozenberg, 2017; Muhammad Ali, 2018; Shi & Varuzzo, 2020).

The conditions under which climate change can have a lasting impact on economic performance are manifold (Warsame et al., 2021). Ahsan et al. (2020) have shown that this affects different economic sectors within countries, creating economic disparities between and within them. Indeed, regions within the same country are not affected in the same way, as the territories' vulnerability level is not the same. Increases in temperature and extreme precipitation lead to losses of physical and human capital (Paglialunga et al., 2022). The downside of this situation is a lasting drop in income, mainly in the least developed territories, resulting in greater economic disparities between regions within countries (Asfaw et al., 2020; Hallegatte et al., 2018).

Considering a situation of insufficient capital for sustainable growth in a territory, more frequent extreme climatic events reduce the probability of the territory leaving its fragile situation. At the same time, they increase the likelihood of others falling into the same situation (Azariadis & Stachurski, 2005). Any localized impact of climate change on a region's growth drivers has a disproportionate effect on its economic performance (Fujita et al., 2001). Thus, climate change affects territories unevenly, creating economic disparities. This highly uneven distribution of the effects of climate change between regions exposes them to a highly climate-dependent economic system, a low capacity for adaptation and resilience, and, therefore, to economic fragility (Cappelli et al., 2021).

Many studies of the effect of climate change on disparities have focused on a single sector, most often agriculture, industry, or tax mobilization. To this end, fiscal stress contributes strongly to regional disparities (Shi & Varuzzo, 2020) due to its close link with the region's ability to provide investment. Yang and Tang (2022) showed that climate change through high temperatures induces regional disparities by affecting tax revenues. They explain that higher temperatures lead to a drop in tax revenues, which reduces the budget mobiliza-

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tion capacities of the regions concerned, creating economic performance gaps between these regions and others.

Chen and Yang (2019) and Zhang et al. (2018) found similar results, stating that high temperatures have a negative effect on firms' production, thus reducing their ability to pay taxes. The result is lower regional tax revenues. In addition, climate change causes losses in agricultural production, which has a negative impact on regional budget revenues. The effect of climate change is not only budgetary or economic but also highly variable. It can render public policies ineffective. In this vein, Dell et al. (2008) show that the impact of climate change on economic activity within regions can be grouped into three main outcomes.

Firstly, high temperatures significantly reduce the economic performance of fragile (poor) territories, in contrast to rich territories where the effect is less pronounced, thus reinforcing disparities between territories. Secondly, they slow down growth rates in poor areas rather than just production levels. Thirdly, high temperatures have a negative impact on agricultural and industrial production and investment in fragile regions. The effect of climate change could exacerbate the gap in economic performance between regions if future values of climate variables follow the same evolutionary trends as historical values.

Among structural factors, the literature confers a principal place to agricultural production (Hallegatte & Rozenberg, 2017; Paglialunga et al., 2022). Cappelli et al. (2021) consider a bidirectional relationship, mechanisms that link climate change-induced disasters, inequality, and vulnerability. Their analysis reveals that territories with higher levels of income inequality suffer damage, and at the same time, inequality increases the number of people affected by disasters. There is thus a vicious circle that keeps certain territories in the disaster-inequality trap, reinforcing economic disparities between regions (Lybbert & Barrett, 2011; Sawada & Takasaki, 2017).

The literature review concludes that the effect of climate change could exacerbate the gap in economic performance between regions. However, the studies have not highlighted the likely effects of proximity in their analyses. Regions sharing borders with others develop proximity relationships that mutually influence their economies.

The aim of this study is to analyze the spatial effect of climate change on regional economic disparities in the context of Benin. Its contribution stems from the paucity of empirical work on the spatial interactions linked to economic disparities between regions of the same country under the influence of climate change. Most works have obscured these spatial interactions in their analysis, accentuating the bias of omitted variables (Benhamed et al., 2023). This paper focuses specifically on the spatial interactions that may exist between climate change and regional economic disparities.

2. METHODOLOGY

Empirically, economic disparities are measured in the literature by indicators of the level of economic performance. The most commonly used indicators include per capita income (the most frequently used), labor productivity, investment, number of active businesses, etc. Following Lazar et al. (2021) and Bourdin (2013), the Gini and Moran indices were calculated using the per capita own revenues of the locality's territories. These are resources derived from the exploitation or sale of the commune's assets (operations concern sand and gravel quarries for construction and public works; asset sales relate to land transactions) and resources from local taxes levied on economic activities. These resources were aggregated and related to the number of inhabitants in the department (unit of administrative division in Benin). Dupuy (2011) and Oțil et al. (2015) consider that economic territorial disparities can be measured by resource indicators, which are resources or tax revenues from the exploitation and sale of the assets of regions, departments, towns, and city districts between the territories studied.

The Gini index can be used to assess inequalities and directly compare the income distribution of two populations, whatever their size. The Moran index (Dubé & Legros, 2014; Anselin, 2010) is used to measure the level of spatial autocorrelation of a variable and to test its significance. Two models are used to estimate the effect of climate change on economic disparities. The first refers to a-spatial model inspired by Paglialunga et al. (2022), and the second refers to a spatial model. In the first model, economic disparities are measured by the Gini index calculated for each department. The specific form of the model is as follows:

$$Gini_{i,t} = \beta_0 + \beta_1 C\lim at_{i,t} + \beta_2 X_{i,t} + \beta_3 \eta_{it} + \varepsilon_{i,t}, \quad (1)$$

where the Gini index measures disparities in per capita own revenue in department i in year t. The climate variable includes the climatic indicators (average temperature and precipitation) that are most widely used as an indicator for measuring climate change. The variable X relates to the main determinants of territorial income distribution approximated by own revenue per capita. η denotes territory-specific potentialities (population density perceived as a specific advantage for economic activities within territories), and ε is the error term. In order to take into account the potential non-linear effects of climate variables, their square has been used in the model.

The spatial model chosen follows the Spatial Durbin Model (SDM) specification. It incorporates a lagged endogenous variable and all lags of explanatory variables (LeSage & Pace, 2009). It remains robust to misspecification, even in the presence of omitted variables. The SDM model remains appropriate in the case of omitted variables that exhibit spatial dependence, sources of correlation between residuals, and explanatory variables. The coefficients obtained from the estimates are unbiased (Soumaoro, 2021). It takes into account spatially dependent and explanatory variables. It uses the marginal effects of explanatory variables of neighboring regions/departments based on the spatial auto-regression model (SAR). The specification for SDM is as follows:

$$Y_{it} = \sum_{j=1}^{N} \rho W Y_{jt} + X_{it}\beta + \sum_{j=1}^{N} \delta W X_{jt} + \mu_i + \lambda_t + \varepsilon_{it} \quad (2)$$

where $Y_{i,t}$: denotes the per capita own revenues of department i at date t; $\Sigma^{N}_{j=1}\rho WY_{jt}$: denotes the per capita own revenues of neighboring departments at date t; $X_{i,t}$ represents the explanatory variables of the model in department i; $\Sigma^{N}_{j=1}\delta WX_{jt}$: are the model's explanatory variables in departments neighboring i; $\mu_i + \lambda_t$: are the individual and temporal effects of department i at time t.

However, spatial interactions can have a dynamic character (Yu & Lee, 2012). Indeed, the value of the explained variable taken for an observation i at time t depends on the value of the explained variable for observation i at the previous period (temporal lag). It also depends on the value of the explained variable for observations neighboring i at period t (simultaneous spatial lag) and finally on the value of the explained variable for observations neighboring i at the previous period $t - 1$ (delayed spatial lag) (Debarsy et al., 2012). In this way, one can think, for example, of spatial diffusion effects, such as a shock occurring in zone i at period t which spreads to neighboring zones in subsequent periods. Table 1 shows explanatory variables.

Table 1. Explanatory variables and expected signs

Label	Nature	Expected sign
Tax revenues	Quantitative (FCFA)	(+/–)
Capital expenditure	Quantitative (FCFA)	(+)
Average temperature	Quantitative (°C)	(+)
Precipitation	Quantitative (mm)	(+)
Heatwave	Dummy	(+)
Population density	Quantitative (h/km^2)	(+/–)
Temperature square	Quantitative (°C)	(–)
Precipitation square	Quantitative (mm)	(–)
Status	Dummy	(+)
Fadec investment	Quantitative (FCFA)	(+)

The status variable indicates the presence or absence of a commune with special[1] status in the department. In addition to the mean temperature and precipitation variables, which are indicators of climate change, a third indicator (dummy variable) has been introduced, taking the value 1 if a heatwave is recorded in department i during year t, and 0 otherwise. A heatwave is defined as an av-

1 According to Law N° 98-005 of January 15, 1999 on the organization of Communes with special status in Benin, Communes with special status are those that meet the following three cumulative criteria: (i) have a population of at least one hundred thousand (100,000) inhabitants; (ii) extend continuously over a distance of at least ten (10) km; (iii) have sufficient budgetary resources to meet operating and investment expenses.

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erage increase in temperature recorded in department *i* at time t compared with the average temperature recorded there between 1900 and 1950 (Paglialunga et al., 2022). Formally, the indicator is defined as *tmv*:

$$tmv_{i,t} = \frac{1}{12}\sum_{m=1}^{12} temperature_{i,t,m} - basse_{temperature}, \tag{3}$$

with

$$basse\_temperature = \frac{1}{50}\sum_{t=1}^{1950} temperature_{i,t,m}. \tag{4}$$

Taking into account the results of the index calculation, a temperature increase greater than 1°C has been considered as the threshold. Thus, the indicator takes the following form:

$$I_{(x=tmv_{i,t})} = \begin{cases} 1; if\ x > 1 \\ 0; if\ x \le 1 \end{cases}. \tag{5}$$

The data used for the estimate are secondary and extracted from the database of the Commission Nationale des Finances Locales (CONAFIL). By Decree No. 2008-274 of May 29, 2008, the Government of Benin created the Commission Nationale des Finances Locales (CONAFIL), which is responsible for, among other things:

(i) collecting and processing economic, financial, and statistical data concerning the communes, with a view to producing reference documents on local finances;

(ii) producing an annual report on the situation of the communes and on essential developments.

CONAFIL has a system for monitoring and evaluating the finances of Benin's communes, based on a local financial database known as Filoc Bénin, which has enabled it to provide users with a series of three summary tables:

(i) the financial summary table,

(ii) the financial balance table and

(iii) the ratio table.

They cover the period from 2003 to 2019. However, missing data constrain the analysis to a 10-year period, i.e., from 2010 to 2019.

Climate data were extracted from the World Bank's Climate Knowledge Portal (CKP).

3. RESULTS

Before interpreting the estimation results, a descriptive analysis is performed. Next, the results of the Gini and Moran indices are presented and interpreted.

Table 2 provides descriptive statistics on own-source revenues by department (unit of administrative division in Benin). It also provides information on the dispersion of these variables. On average, across the twelve departments, own-source revenue per inhabitant is around 2,403 FCFA. The minimum varies between 445.3 FCFA for Donga and 7,830.4 FCFA for Littoral. As for the maximums, Couffo has its own revenue of 1,235.8 FCFA and Littoral of 15,486.9 FCFA. There is thus a disparity between departments in the mobilization of their own revenue per inhabitant. The Littoral department tops the ranking with an average per capita own revenue of 12,923 FCFA over the 2010–2019 period, followed by Ouémé, 2,663 FCFA, and Atlantique, 2,303 FCFA. The other departments follow a similar ranking, with low and diverging values. The standard deviation thus provides information on the dispersion of earnings per capita and highlights the existence of economic disparities between departments.

Figure 1 shows trends in own revenues per capita per department. Analysis reveals a sustained trend, with wide variations over time between departments. The trend has been uneven, with both upward and downward movements. The department of Atlantique saw a steady and sustained rise over the period under review, which justifies its ascent favored by its inclusion among the departments with special-status communes.

The departments of Littoral, Zou, Plateau, and Ouémé have similar trends, showing an erratic pattern over 2013–2019. These departments experienced flooding between 2010 and 2019, cre-

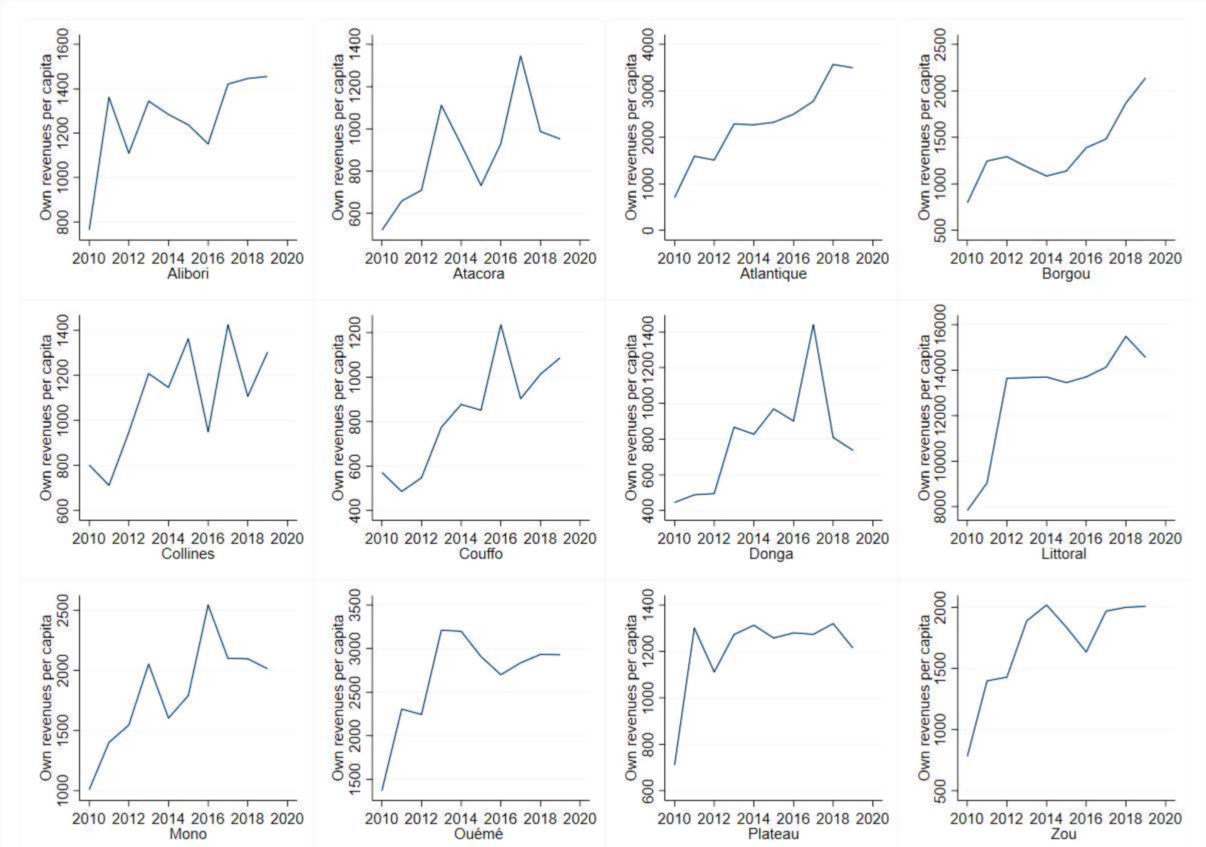

Figure 1. Trends in per capita revenues by department

Table 2. Descriptive statistics for own-source revenues per capita (in FCFA*)

Department	Mean	Standard deviation	Minimum	Maximum
Alibori	1257.37	210.74	762.20	1455.61
Atacora	887.25	240.71	519.76	1346.29
Atlantique	2303.27	880.65	703.46	3568.96
Borgou	1361.44	391.45	793.40	2140.87
Collines	1096.72	239.29	711.96	1425.39
Couffo	834.81	245.06	485.82	1235.76
Donga	797.98	293.30	445.31	1440.45
Littoral	12923.58	2454.87	7830.44	15486.87
Mono	1815.76	437.55	1009.39	2543.03
Ouémé	2663.23	558.05	1367.87	3211.21
Plateau	1205.27	184.27	709.90	1319.95
Zou	1696.99	398.77	779.41	2019.85
Mean	2403.64	544.56	1343.24	3099.52

Note: * 655,957 FCFA (XOF) = 1 EURO (€).

ating major losses. 4,828 homes were completely destroyed and communication routes rendered impassable (Aho et al., 2018; MCVDD, 2022). This damage slowed down economic activities within these departments, thus affecting resource mobilization. The departments of Atacora, Donga, Mono, and Couffo also recorded floods destroying 14,500 hectares of agricultural production and household economic activities (Hountondji, 2022). The destruction of crops, livestock, and household economic activities is not conducive to the satisfactory mobilization of economic resources in the communes making up these departments. As for the departments of Collines and Alibori, they have also experienced the same extreme climatic events, leading to a slowdown in economic activi-

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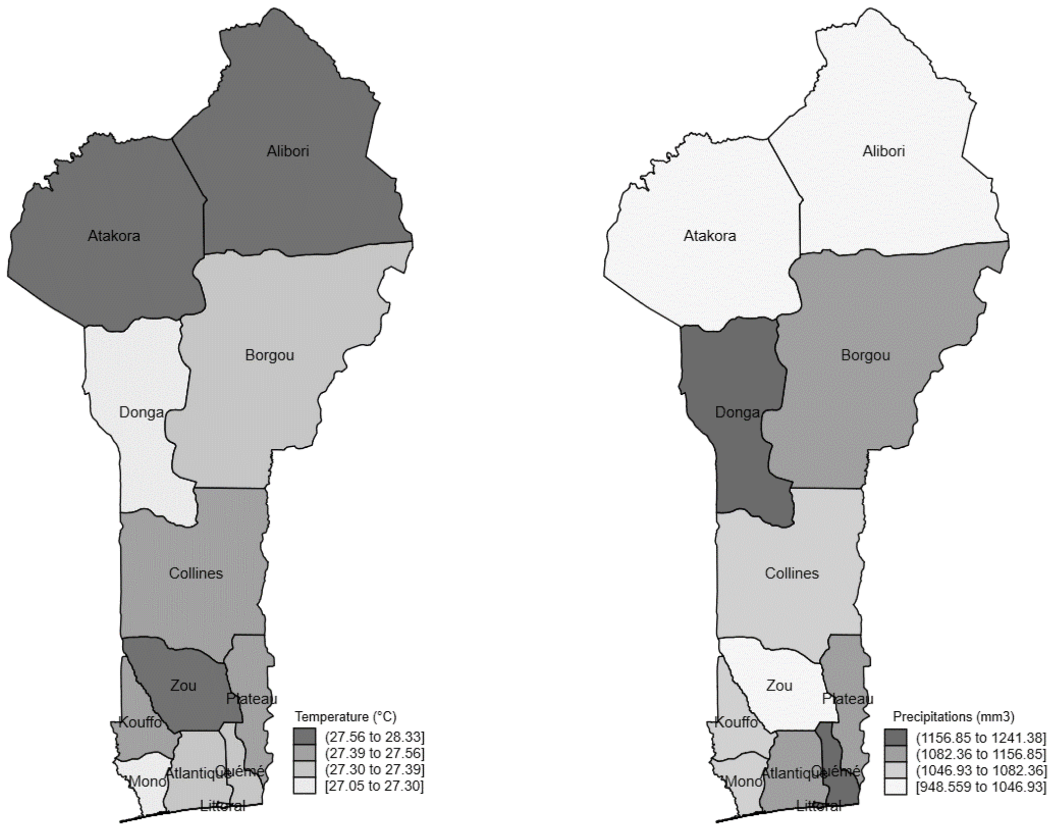

A. Average temperature **B.** Precipitations

Note: The darker the color, the higher the value of the observed variable.

Figure 2. Spatial distribution of mean temperature and precipitation

ties and a drop in revenue mobilized by their territory. Emergency support policies implemented by the central government and/or development institutions helped them to return to full capacity. Unlike all these departments, Atlantic and Borgou did not experience any climatic events during the 2013–2015 period. This may justify the growing pace of own-source revenue mobilization in these two departments.

Figure 2 shows the spatial distribution of mean temperature and precipitation by department.

Figure 2 shows that the Atacora, Alibori, and Zou departments are the hottest (Figure 2a) and the least watered (Figure 2b). In contrast to these first three, other departments record varied statistics. Indeed, the hottest areas are not necessarily those with the lowest rainfall. The hills are in the third quartile for mean temperature distribution and in the second quartile for rainfall distribution. This situation can be explained by the climatic disturbances observed and the frequent and intense rainfall, which are consequences of the manifestations of climate change that are likely to affect economic disparities between departments.

Table 3 shows the results of the Gini index calculated by department. It provides an analysis of inequalities in per capita own-source revenues within departments.

The results show that per capita own revenues within departments are unevenly distributed, with a higher average value of 0.388 in Zou. This is followed by Borgou and Atlantique, with average values of 0.382 and 0.342, respectively. Donga has the lowest average value of 0.17, which identifies it as the department with the least unequal distribution of own revenues per inhabitant, as shown in Figure 2. The department of Zou confirms this

Table 3. Gini index of own revenues per capita in departments

Department	Gini index		
	Mean	Min	Max
Alibori	0.222	0.150	0.305
Atacora	0.291	0.188	0.406
Atlantique	0.343	0.298	0.471
Borgou	0.382	0.298	0.472
Collines	0.286	0.193	0.389
Couffo	0.330	0.232	0.422
Donga	0.172	0.099	0.349
Littoral	–	–	–
Mono	0.309	0.248	0.351
Ouémé	0.324	0.203	0.437
Plateau	0.204	0.147	0.248
Zou	0.388	0.301	0.520

inequality, with a maximum index of 0.52 over the 2010–2019 period. As the Littoral department comprises a single commune (Cotonou), the Gini index could not be calculated.

Figure 3 shows the spatial distribution of the average Gini index across departments.

Figure 3 shows that the departments of Plateau and Donga show less disparity in terms of per capita own revenues. The Atlantic, Zou, and Borgou have more pronounced revenue disparities. Couffo, Mono, and Ouémé are in the same categories, while Collines, Atacora, and Alibori are in the less unequal categories.

Note: The darker the color, the higher the value of the observed variable.

Figure 3. Spatial distribution of the average Gini index within departments

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Table 4. Moran index

Variable	Years	I (Moran)	E(I)	Sd(I)	Z	p-value
Own revenue per capita	2010	–0.074	–0.091	0.027	0.611	0.271
	2011	–0.029	–0.091	0.034	–1.840	0.033**
	2012	–0.061	–0.091	0.028	1.065	0.143
	2013	–0.027	–0.091	0.032	2.021	0.022**
	2014	–0.028	–0.091	0.032	1.975	0.024**
	2015	–0.03	–0.091	0.031	1.974	0.024**
	2016	–0.033	–0.091	0.031	1.872	0.031**
	2017	–0.038	–0.091	0.030	1.799	0.036**
	2018	–0.028	–0.091	0.032	1.949	0.026**
	2019	–0.029	–0.091	0.033	1.858	0.032**

Note: Neighborhood type: inverse distance; (**) Significant at the 5% error threshold.

The spatial dynamics of the distribution of earnings per capita are assessed by Moran's spatial autocorrelation index presented in Table 4.

Analysis reveals a negative spatial autocorrelation (dispersion), most significant at the 5% threshold for own revenues per capita. Negative values of the index mean that own revenues are not concentrated in the same neighborhood. The evolution of Moran's I index identified the spatio-temporal dynamics of the degree of concentration of own earnings per capita, which is following an upward trend. This means that, over the years, own revenues tend to be increasingly concentrated in the same neighborhood.

Following equation 1, the Hausman test was used to estimate a random-effects model. The estimation results are shown in Table 5.

The results indicate that average temperature and precipitation positively and significantly affect economic disparities within territories in line with the results. The heatwave index is not significant. This may be due to the temporal dimension or to the small difference in the increase recorded. Analysis reveals that average temperature has a significant positive effect, at the 10% threshold, on economic disparities within territories. Precipitation also has a positive and significant effect at the 5% level. Climate change reinforces economic disparities within departments and does not favor an egalitarian distribution of per capita revenues. A 1-point increase in average temperature leads to a 4.4-point increase in economic disparities within departments. A 1-point increase in precipitation leads to a 0.001-point increase in economic disparities. Extreme weather conditions, favored by high temperatures or pre-

Table 5. Effect of climate change on regional economic disparities using the random-effects model

Gini			Coef.	Std. Err.	t
Population density			–0.000	0.000	–0.49
Average temperature			4.380*	2.411	1.82
Precipitation			0.001**	0.000	2.35
Communes with special status			0.025	0.026	0.98
Heatwave (tmv)			–0.017	0.019	–0.89
Temperature square			–0.078*	0.042	–1.83
Precipitation square			–6.85E-07**	2.69E-07	–2.55
Log of tax revenues			0.060***	0.019	2.99
Log investment expenditure			–0.000	0.010	–0.07
Fadec investment			–2.29E-08**	1.05E-08	–2.18
_cons			–62.492*	33.906	–1.84
R-sq	Within	0.0947	Prob > chi2 = 0.0000		
	Between	0.5671			
	Overall	0.3358			

Note: *** $p < 0.01$; ** $p < 0.05$; * $p < 0.1$.

cipitation, are therefore not conducive to the mobilization of local revenues.

Considering the economic structure of the departments, this negative effect of climate change would be transmitted in particular by the agricultural sector. Indeed, the results of the 2019 National Agricultural Census show that, on average, 50% of the population carried out their main income-generating activity in agriculture in the departments of Alibori, Atacora, Borgou, Collines, Couffo, and Donga. The departments of Mono, Plateau, and Zou have just over 35% of their population engaged in agriculture (DSA, 2021). As agriculture is a highly climate-dependent sector, climatic extremes are not conducive to good production, thus affecting the mobilization of resources by communes within departments. This situation weakens the mobilization of local resources and maintains economic disparities.

The results of the spatial effects analysis are presented in Table 6 and show the direct, indirect, and total effects of climate change on economic disparities. Indeed, the results of an initial estimation of the non-dynamic, fixed-effect Durbin Spatial Model (SDM) (Appendix A) show that for climate variables, significant effects are obtained at the level of total long-term effects (total LR) and main effects. The model's spatial rho is negative and significant at the 10% threshold, meaning that there are significant negative spatial externalities from economic activity and shocks between departments. This does not rule out the possibility that spatial interactions may be dynamic in nature. Thus, the values taken for an observation *i* at a period of time *t* may depend on the values taken by observations neighboring *i* at the previous period.

Analysis reveals that there are main, indirect, and total effects, both short- and long-term, between climate variables and per capita own earnings, with a positive rho space that is significant at the 1% level. It emerges that a one-point increase in average precipitation in neighboring territories (Wx) leads to a 0.005% increase in own revenues per capita in a given territory at the 5% threshold. A one-point increase in precipitation in a given region (department) leads to a 0.004% increase in own revenues in neighboring territories at the 5% threshold, both in the short (SR indirect) and long (LR indirect) term. Analysis of total effects shows

Table 6. Effect of climate change on regional economic disparities using the dynamic panel SDM model

Log own revenues/ per capita	Main	Wx	SR direct	SR indirect	SR total	LR direct	LR indirect	LR total
Population density	–0.000	0.002*	–0.000	0.001*	0.001*	–0.000	0.001*	0.001*
	(0.000)	(0.001)	(0.000)	(0.001)	(0.001)	(0.000)	(0.001)	(0.001)
Average temperature	6.485	0.471	7.265	–2.329	4.936	7.479	–2.448	5.032
	(4.405)	(9.483)	(4.735)	(8.017)	(7.036)	(4.887)	(8.228)	(7.177)
Precipitation	0.001	0.005**	0.000	0.004**	0.005***	0.000	0.004**	0.005***
	(0.001)	(0.002)	(0.001	(0.002)	(0.002)	(0.001)	(0.002)	(0.002)
Mean temperature squared	–0.118	0.015	–0.134*	0.062	–0.072	–0.138	0.064	–0.074
	(0.076)	(0.165)	(0.081)	(0.139)	(0.124)	(0.084)	(0.143)	(0.126)
Precipitation squared	–0.000	–0.000**	–0.000	–0.000*	–0.000***	–0.000	–0.000*	–0.000***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Log tax revenue	0.598***	0.367***	0.583***	0.117	0.700***	0.599***	0.114	0.713***
	(0.043)	(0.116)	(0.040)	(0.079)	(0.099)	(0.041)	(0.081)	(0.101)
Log investment	0.051	–0.080	0.060	–0.082	–0.022	0.062*	–0.084	–0.022
	(0.037)	(0.084)	(0.034)*	(0.067)	(0.072)	(0.035)	(0.069)	(0.073)
Fadec investment	–0.000	–0.000**	–0.000	–0.000*	–0.000**	–0.000	–0.000*	–0.000***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Spatial rho	0.374***		–					
Variance sigma2_e	0.005***		–					
R-sq	between	0.5735	–					
	within	0.4378	–					
	overall	5272	–					
Log-likelihood	–885.6386		–					

Note: * $p < .1$; ** $p < .05$; *** $p < .01$; Standard errors in parentheses.

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that a one-point increase in precipitation leads to a 0.005% increase in own revenues at the 1% threshold, also in the short and long term. The sign of the mean temperature does not appear significant. Thus, good rainfall at the right time favors good harvests, which are a source of trade and supply for the agro-industry, leading to increased trade on local and regional markets. The income generated and the local taxes levied on these activities improve not only per capita revenues but also the territories' own revenues.

However, the square of the mean temperature appears significant and negative in the short term, with a direct effect. In fact, a one-point increase in mean temperature squared results in a 0.134% reduction in per capita own earnings. This shows that extreme temperatures have negative short-term effects on the mobilization of own-source revenues by regions. This confirms the results obtained with the random effects model. The precipitation square also produces negative short- and long-term effects. Extreme precipitation events induce negative externalities on neighboring regions. These interactions thus maintain economic disparities between regions.

The positive and significant sign of spatial rho in the dynamic model, at the 1% threshold, indicates the existence of positive spatial externalities between territories.

4. DISCUSSION

The results highlighted the existence of economic disparities within and between departments (unit of administrative division in Benin). The Moran index proved a spatial autocorrelation between per capita own revenues, with a dynamic of concentration in the same vicinity over the years. Variations in temperature and precipitation, in the absence of spatial effects, accentuate economic disparities within territories. On the other hand, in the presence of dynamic spatial effects, positive spatial externalities appear. Positive variations in precipitation in one department, therefore, imply an increase in per capita revenues in neighboring departments, and vice versa. The damage caused by climate change in one area encourages a positive economic dynamic in the neighboring area.

The results of the non-dynamic and dynamic spatial models show that the role of neighborhood is not neutral in explaining economic disparities. Across total, main, and indirect effects, positive variation in climatic variables in one territory favors the mobilization performance of own revenues in neighboring territories. An increase in temperature and/or precipitation in one territory can cause inconvenience and redirect economic activities to the neighboring territory. This detour of trade increases its usual demand for goods and services, thus revitalizing the mobilization of own revenues. This phenomenon fosters the economic disparities observed between territories, making some poor and enriching others. Spatial interactions reinforce economic differences and accentuate disparities between regions.

These results are in line with those obtained by Paglialunga et al. (2022) and Beguerang (2023), who show that climate change significantly affects territories in unequal ways. It creates disparities by weakening activities within the territories concerned (Montador, 2022). Yang and Tang (2022) reinforce these conclusions by showing that climate change induces very high local budgetary pressure, which accentuates regional inequality. Dell et al. (2008) corroborated these results, demonstrating that climate change exacerbates the economic development gap between territories.

On the other hand, the results show the existence of a non-linear relationship between climatic variables and disparities. Above a certain level, climatic variables and inequalities evolve in opposite directions. These results would seem to illustrate an inverted-U relationship between climate variables and economic disparities. At the first stage of development, which does not yet favor a more egalitarian economic distribution, territories would be more vulnerable to the effects of climate change. In the second stage, the effect is reversed, i.e., an advanced level of economic development would make territories less vulnerable to the effects of climate change. Similar results are obtained by Berlemann and Wenzel (2018) and Cappelli et al. (2021), showing that climate change represents a burden for territories unable to protect themselves from shocks.

Benhamed et al. (2023) indicate that climate change has direct and indirect impacts on economic performance in both the short and long term. However, unlike the present results, these externalities are negative. This difference in results can be explained by the unit of analysis, which is the country in their work and the regions within the country in the case of this study. Indeed, interactions between regions within a country are more direct than those between countries. The negative impacts of climate change can adversely affect trade interactions between countries, thus generating negative externalities. De Siano et al. (2020) and Soumaoro (2021) have shown that climate change induces direct and indirect spatial effects, as do the present results. However, these authors focused on a single sector. The first focused on the energy sector, and the second on the agricultural sector.

The present study would gain more if it had data on a long series or data on the production of Benin's regions. An analysis exploring the effect of climate shocks on regional growth drivers, such as human capital and innovation, would also enable a more in-depth analysis of regional disparities under the influence of climate change in Benin. These avenues for reflection represent interesting prospects for deepening the understanding of the spatial effects of climate change.

CONCLUSION

The aim of this paper was to analyze the spatial effect of climate change on regional economic disparities in the context of Benin. The results revealed not only the presence of economic disparities between territories but also how climate change positively affects and reinforces these disparities, with significant neighborhood effects. These results imply a strengthening of territories' capacities for adaptation and resilience to climate change through investment in climate-resilient infrastructures, such as the construction of modern markets offering adaptation possibilities. This modernization can be complemented by climate-sensitive investments, including the construction of carbon sinks and a climate-sensitive local development plan. Each department must support the integration of climate change into the annual programming and budgeting process at the local level through development and investment plans. In the future, with data on a long series or on regional output, the study could explore the effect of climate shocks on regional growth drivers such as human capital, consumption, and innovation to deepen the analysis of regional disparities under the influence of climate change. These results would then support climate-sensitive policies, incorporating a correction of the effects of economic disparities when the causes are mapped and the transmission channels are clearly identified.

AUTHOR CONTRIBUTIONS

Conceptualization: Christian Duhamel Logozo, Hortensia Acacha-Acakpo, Denis Acclassato-Houensou, Sylvain Hekponhoue.
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Investigation: Christian Duhamel Logozo.
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Supervision: Hortensia Acacha-Acakpo, Denis Acclassato-Houensou, Sylvain Hekponhoue.
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Writing – original draft: Christian Duhamel Logozo.
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APPENDIX A

Table A1. SDM estimation in fixed-effect panel

Log own revenues/per capita	Main	Wx	LR direct	LR indirect	LR total
Population density	0.000	0.001	0.000	0.001	0.001*
	(0.000)	(0.001)	(0.000)	(0.001)	(0.001)
Average temperature	7.923*	3.322	7.628	1.293	8.920
	(4.787)	(10.739)	(5.051)	(9.719)	(8.451)
Precipitation	0.000	0.004	0.000	0.003	0.003*
	(0.001)	(0.003)	(0.001)	(0.002)	(0.002)
Mean temperature squared	–0.148*	–0.041	–0.144	–0.006	–0.149
	(0.083)	(0.187)	(0.087)	(0.169)	(0.148)
Precipitation squared	0.000	0.000	0.000	0.000	0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Log tax revenue	0.577***	0.206*	0.575***	0.060	0.635***
	(0.038)	(0.108)	(0.037)	(0.077)	(0.090)
Log investment	0.024	–0.062	0.028	–0.062	–0.034
	(0.028)	(0.068)	(0.029)	(0.055)	(0.066)
Fadec investment	0.000	0.000	0.000	0.000	0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Spatial rho	–0.260*	–			
Variance sigma2_e	0.006***	–			
R-sq	Within	0.7796	–	–	–
	Between	0.5669			
	Overall	0.6316			
Log-likelihood	128.9895				

Note: * $p < .1$; ** $p < .05$; *** $p < .01$; Standard errors in parentheses.

Table A2. Pairwise correlations

No.	Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
(1)	Gini index	1.000	–	–	–	–	–	–	–	–	–
(2)	Population density	0.173	1.000	–	–	–	–	–	–	–	–
(3)	Average temperature	–0.178	–0.223*	1.000	–	–	–	–	–	–	–
(4)	Precipitation	0.119	0.382*	–0.563*	1.000	–	–	–	–	–	–
(5)	Mean temperature squared	–0.180	–0.225*	1.000*	–0.563*	1.000	–	–	–	–	–
(6)	Precipitation squared	0.101	0.392*	–0.539*	0.996*	–0.539*	1.000	–	–	–	–
(7)	Log tax revenue	0.348*	0.422*	0.241*	–0.043	0.238*	–0.022	1.000	–	–	–
(8)	Log investment	0.109	0.188*	0.273*	–0.306*	0.271*	–0.282*	0.680*	1.000	–	–
(9)	Fadec investment	–0.067	0.085	0.394*	–0.623*	0.392*	–0.617*	0.416*	0.654*	1.000	–
(10)	Log own revenues	0.274*	0.650*	0.065	0.069	0.062	0.085	0.864*	0.597*	0.345*	1.000

Note: * shows significance at $p < 0.05$.