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RESEARCH ARTICLE

Population and Economic Growth in Mexico: Regime Dynamics and Causality

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Abstract

This paper examines the joint dynamics of population and economic performance using panel data from the 32 Mexican states throughout the period 1940-2020. The analysis considers the population growth rate and per capita GDP level as state variables. In the first stage, it applies regime dynamics and hierarchical cluster analysis to segment the sample into regimes of Mexican states with similar trajectories in terms of population and per capita GDP. In the second stage, after identifying clusters that exhibit internal homogeneity and are distinct from one another, the study conducts Granger, VAR causality, and cointegration tests, both with and without accounting for structural changes. The results confirmed that there is a causal relationship between population and economic growth, with the nature of this relationship varying between positive and negative effects, depending on the cluster and stage identified by a single structural change. However, no further evidence of causality emerges beyond the breakpoint.

Keywords: Hierarchical cluster analysis, population dynamics, economic growth, panel causality test.
JEL codes: C14, C38, J10

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1. Introduction

The complex relationship between population dynamics and economic growth stands as a foundational pillar within economic theory and has been the subject of extensive scrutiny over an extended period. Policymakers, demographers, and economists universally agree on the utmost importance of understanding this complex interplay. For several decades, there has been an ongoing discussion concerning the potential impact of rapid population growth on a nation's economic growth and overall well-being. In addition to the theoretical discourse, the availability of extensive, trustworthy databases for an increasing number of countries has not only enabled[1] but also catalyzed a substantial surge in empirical studies in this particular direction. Nevertheless, neither the theoretical front nor the empirical analyses have reached anything that resembles a consensus. On the contrary, the conclusions and results are discordant. In particular, the hypotheses and empirical analyses regarding the causal relationship, are inconclusive. Not only are none of the possible outcomes ruled out, but all potential results have been observed.

Despite numerous studies focusing on developing countries, only a limited few choose Mexico as their unit of analysis. Mexico presents some singularities that are especially relevant for analyzing the links between population growth and economic performance. According to the latest data from the United Nations[2], it currently holds the tenth position in the list of the world's most populous countries, having moved up from the eleventh spot in the previous report. Although it has experienced some of the stylized facts of the demographic transition, it stands out for certain peculiarities. The initial stages of this transition are marked by an initial reduction in mortality, shortly followed by a decrease in fertility. During the 1940s, Mexico witnessed a significant decrease in its mortality rate, as the established facts suggest. However, the behavior of the fertility rate diverged from the conventional demographic transition pattern. It witnessed an increase between the 1940s and 1960s, and it was not until the late 1960s that a decline began. As a result, during the period from 1940 to 1970, Mexico recorded one of the highest population growth rates in the world. This spectacular population growth took place under the influence of an openly natalist public policy (Cabrera, 1994) and in conjunction with an agrarian reform that encouraged and solidified peasant population. This development coincided with significant modernization reforms that facilitated a remarkable period of economic growth, often referred to as "the Mexican miracle". It is worth noting that this phenomenon was not homogeneous throughout the entire Mexican territory. Instead, it exhibited profound disparities in terms of economic performance among the 32 Mexican states (hereafter referred to as "MS") (Alba and Potter, 1986). Starting in the 1970s, the positive correlation between population -which was starting to slow down- and economic growth -which had captured the interest of the researchers at the time[3] - underwent a radical transformation in every aspect. The population policy shifted its focus toward birth control, achieving the expected outcome of a significant reduction in the fertility rate in a relatively short period. Concurrently, the exceptional per capita economic growth, averaging around 6% annually from 1940 to 1970, gave way to a noticeable deceleration, with per capita growth rates averaging 2% up to the present day. This slowdown was punctuated by macroeconomic crises of both domestic origin (in 1982, 1986 and 1995) and international origin (such as the 1970s oil crisis and the global economic crises of 2001 and 2008). The aforementioned process did not occur uniformly throughout the Mexican territory. With diverse approaches, several empirical studies (Brida et al., 2013; Mendoza-Velázquez et al., 2020; Brida et al., 2021) provide evidence of a great diversity of growth and development patterns among the MS.

[1] The Penn Tables of the Maddison Project (Maddison, 1995) provided standardized statistics of GDP per capita across countries and gave considerable impetus to the comparative analysis of the interaction between population and economic growth.

[2] United Nations Department of Economic and Social Affairs, Population Division (2022).

[3] "Mexico presents a puzzling picture for those who expound a simple version of the "demographic transition", the name that has come to be given to the theory that modernization brings predictable changes in mortality and fertility" (Coale, 1977, p.423).

This paper examines the dynamic relationship between population growth and economic performance (levels and rates of growth) using panel data from 1940 to 2020 for all the 32 MS. To account for Mexico's demographic and economic diversity, we utilize a method that entails grouping these states based on the similarity of their population growth and per capita GDP trajectories. Neglecting to account for the heterogeneity within a panel dataset introduces the risk of yielding spurious evidence of causality based on a limited number of MS that happen to exhibit the desired relationship. To consider a single sample of the 32 MS with markedly diverse trajectories would weaken the strength of the results. Previous studies that analyzed the same relationship for large groups of countries considered heterogeneity by dividing the sample on a single criterion (level of development, population size, geography or culture). In order to extend this literature, we propose grouping MS based on two characteristics: population growth and economic performance. The multidimensional nature of the relationship is best captured by considering more than one characteristic. In this paper, we apply a non-parametric technique that classify the MS based on the similarity of the joint behavior of population growth rates and economic performance (measured by per capita GDP) during the period of analysis. In the second stage, we examine the causal relationships between population and economic growth. We delineated econometric models for each of the groups and then for the entire sample as a whole. For each econometric model, we apply a Granger causality analysis and cointegration tests. Furthermore, we explore these hypotheses while considering the possibility of a change in the relationship at a specific point in time. Ignoring structural changes could obscure true causality, as it is demonstrated that these breaks can introduce non-stationarity in time series residuals. Failing to account for the presence of structural breaks may result in invalid inferences (Baltagi et al., 2016). This issue has prompted extensive research into unit root tests in the presence of structural breaks or regime shifts (Perron, 1990; Banerjee et al., 1992; Zivot and Andrews, 2002; Gregory and Hansen, 1996).

If a causal relationship between population and income exists in a specific MS, it is probable that this relationship extends to the remaining states within the same homogeneous group. Conducting cluster analysis prior to estimation enhanced our efficiency compared to analyzing the entire panel, which comprises MS with diverse economic dynamics.

Our paper contributes to the empirical literature that investigates the causal links between population and economic growth in various ways. Focusing on Mexico as the unit of analysis, we utilize a dataset compiled by Germán-Soto (2005, 2015) containing disaggregated annual data for each of the 32 MS over an 80-year period. To identify groups of MS that have exhibited similar dynamic trajectories during the analysis period, we employ a non-parametric technique. This approach allowed us to divide the sample according to two dimensions, population dynamics and the evolution of GDP per capita, instead of basing it on a single criterion such as geography, culture, demography or economy, as some previous studies have done. This, in turn, enabled us to more efficiently conduct panel Granger causality analyses for each group. The present study also contributes to the discussion on causality between population and economic growth. Importantly, we consider the role of structural change in this relationship, which has been previously overlooked in the literature. Failing to account for this aspect could lead to misleading results. Garza-Rodriguez et al. (2016) have undertaken some analysis in this direction, yet they did not explore hierarchical regimes and omitted the period before 1960. This is noteworthy, as this earlier stage witnessed significant changes in both fertility rates and economic growth in Mexico.

The remainder of the paper is organized as follows. Section 2 presents a concise review of the main growth theories and empirical studies that have explored the relationship between population and economic growth. Section 3 introduces the data used for defining regimes and applies symbolic time series analysis and clustering methodologies, which include the Minimum Spanning Tree (hereafter referred to as "MST") and the Hierarchical Tree (hereafter referred to as "HT"). These methods were employed to create homogeneous groups of MS, based on their population growth and economic performance. After the formation of the clusters, section 4 presents an econometric analysis in which we tested causality within each cluster and across the entire panel. Finally, in Section 5, we offer concluding remarks, reflections, discuss the limitations of our work, and outline possible avenues for future research.

2. Population and economic growth: a literature review

From the inception of economic theory, population dynamics have consistently held a key role. Despite the importance that all schools of thought give to the interplay between population and economic growth, consensus remains elusive concerning the causality of this relationship and, indeed, its existence. Broadly speaking, the central discussion revolves around the potential effects of rapid population growth on per capita income.

According to the neoclassical growth model, as elucidated by the model of Solow (1956), a negative relationship is predicted. A higher population growth rate is anticipated to decelerate capital accumulation during the transition to the steady state, ultimately resulting in a lower long-term equilibrium product. The underlying mechanisms for this phenomenon are attributed to the dilution effect and diminishing marginal returns. Nonetheless, it is essential to note that in the context of this model, the population is typically considered exogenously, growing at a constant rate. Consequently, it does not take into consideration the mutual effects the two variables might exert on each other, nor the effects of economic growth on population dynamics.

Many of the empirical literature that addresses this issue does so by relying on the theoretical framework provided by the neoclassical model. In the pioneer study conducted by Coale and Hover (1958) on the case of India, they conclude that rapid population growth constrains the per capita income. The authors suggest that high fertility rates result in a reduced labor supply proportion and lower level of per capita product. At the same time, a higher dependency ratio diverts resources that limit economic growth. However, studies executed by Kuznets (1967), Thirlwall (1972), and Simon (1989), among others, which utilized regression analysis with cross-sectional data, failed to provide conclusive evidence of a negative relationship. In some instances, albeit not statistically significant, a positive association is observed.

Contrary to the predictions of the neoclassical model, the optimistic viewpoints of Boserup (1965) and Kremer (1993), among others, emphasize the increased opportunities for specialization, division of labor, and productivity enhancements that stem from a growing population. Boserup (1965) highlights how demographic pressure induces technological change. In certain endogenous growth models (Romer, 1986, 1990), population growth contributes to economies of scale. Beyond its role as labor force, the population assumes a central position in these models. It serves as the wellspring from which scientists and innovators emerge. Its size dictates the pace of technological advancement; the larger the population, the higher the likelihood of housing a genius within it. At the same time, a larger population stimulates a demand for innovative goods, which in turn, reshapes the endowment of human capital, thereby impacting productivity (Kremer, 1993). Additionally, a larger population leads to increased population density, enabling greater efficiency in the delivery of public services such as education, healthcare, urban transport, among others, and contributing to agglomeration externalities (Krugman, 1991).

Other studies adopt the classical approach of treating the population as an endogenous variable, where its evolution is determined by the model's variables. Galor and Weil (2000), Hansen and Prescott (2002), Irmen (2004), Mierau and Turnovsky (2014), and more recently Bucci et al. (2019), among others, have developed models where the relationship between population growth and economic growth is not monotonous. Moreover, there is feedback, and the mutual effects change in direction and magnitude during the transition.

On the empirical front, the substantial body of literature on this subject dates back to the 1980s. The publication of the Madisson database and its subsequent updates allowed researchers to access a vast and reliable dataset encompassing an expanding number of countries. This accessibility not only permitted but also encouraged the examination of the connections between population and economic growth through the application of cointegration and Granger causality analysis (Granger, 1969). Table 1 summarizes the characteristics and main findings of some of these investigations.

Table 1: *Empirical literature surveyed*

Author	Period	Sample	Estimation Method	Findings
Jung and Quddus (1986)	1950 - 1980	44 countries	Granger Causality test	$p \Rightarrow^{+} y$ $p \Rightarrow^{-} y$ $y \Rightarrow^{+} p$ $y \Rightarrow^{-} p$ Non causality
Kapuria-Foreman (1995)	1961 -1991	Nepal	Granger Causality test	$p \Rightarrow^{(+)} y$
	1961 -1990	India		$p^{(+)} \Leftrightarrow^{(-)^{**}} y$
	1953 -1989	China		$p^{(-)} \Leftrightarrow^{(+)^{**}} y$
	1951 -1990	Ghana		$y \Rightarrow^{(-)} p$
	1953 -1989	Sri Lanka		$y \Rightarrow^{(-)} p$
	1961 -1991	Bolivia		Non Causality
	1949 -1991	Philippines		Non Causality
	1952 -1991	Guatemala		$p \Rightarrow^{(+)^{**}} y$
	1961 -1990	Syria		$y \Rightarrow^{(-)} p$
	1961 -1990	Peru		$y \Rightarrow^{(-)^{*}} p$
	1951 -1990	Thailand		Non Causality
	1958 -1990	Turkey		$p^{(-)} \Leftrightarrow^{(+)^{**}} y$
	1961 -1990	Chile		$p^{(-)} \Leftrightarrow^{(+)^{**}} y$
	1952 -1990	Argentina		Non causality
	1948 -1986	Mexico		$p \Rightarrow^{(+)^{**}} y$
Nakibullah (1998)	1960 - 1990	Bangladesh	VAR	$y \Rightarrow^{+} p$
Dawson and Tiffin (1998)	1950 - 1993	India	Cointegration (Johansen)	Non Causality
Darrat and Al-Yousif (1999)	1950 - 1996	20 countries*	Cointegration VEC	$p \Rightarrow^{(+)^{*}} y$
Thornton (2001)	1925 -1994 1921 - 1994 1913 - 1994	Colombia Mexico Peru	Granger Test VAR	Non Causality
Li and Zhang (2007)	1978 - 1998	China	VI - GMM	$p \Rightarrow^{(-)} y$
Furuoka (2009)	1961 -2003	Thailand	Cointegration (Johansen), VEC	$p \Rightarrow^{+} y$
Hasan (2010)	1952 - 1998	China	VAR VEC	$y \Rightarrow^{-} p$
Mulok et al. (2011)	1960 - 2009	Malaysia	Cointegration (Johansen), VAR, Toda-Yamamoto	Non Causality
Yao et al. (2013)	1952 - 2007	China	Cointegration, VECM	$p \Rightarrow^{(-)} y$
Liu and Hu (2013)	1983 - 2008	provinces China (panel)	Regression	$p \Rightarrow^{(-)} y$
Mahmud (2015)	1980 -2013	India	Cointegration (Johansen), VEC	$y \Rightarrow^{+} p$
Furuoka (2018)	1961 - 2014	China	ARDL	$p \Leftrightarrow y$

Continued on next page

Table 1 – *Continued from previous page*

Author	Period	Sample	Estimation Method	Findings
Tsen and Furuoka (2005)	1950 - 2000	Japan, Korea, Thailand China, Singapore, Philippines Honk Kong, Malaysia Taiwan, Indonesia	Cointegration (Johansen) VAR	$p \Leftrightarrow y$ $p \Rightarrow y$ $y \Rightarrow p$ Non causality
Yao et al. (2007)	1954 - 2005	Taiwan	Cointegration (Johansen), VAR, Toda-Yamamoto	until 2000 $p \Rightarrow^{+} y$ until 2005 insignificant
Huang and Xie (2013)	1980 - 2007	Panel 90 countries	simultaneous ADL	$p \Rightarrow^{-} y$
Ali et al. (2013)	1975 - 2008	Pakistan	ARDL	$p \Rightarrow^{+} y$
Chang et al. (2017)	1870 - 2013	Finland, France, Portugal, Sweden Canada, Germany, Japan, Norway, Switzerland Austria, Italy Belgium, Denmark, Netherlands, UK, US, New Zealand	Panel Granger Causality Test	$p \Rightarrow y$ $y \Rightarrow p$ $p \Leftrightarrow y$ Non Causality
Garza-Rodriguez et al. (2016)	1962 - 2012	Mexico	VEC	$y \Leftrightarrow p$
Rahman et al. (2017)	1960 - 2013	USA, UK, Canada China, India, Brazil	Panel cointegration VEC	$p \Rightarrow^{+} y$
Chirwa and Odhiambo (2019)	1970 - 2015	Zambia	Cointegration (Johansen) ADL	$p \Leftrightarrow y$
Aksoy et al. (2019)	1970 - 2014	21 OECD countries	Panel VAR	$p \Rightarrow^{+} y$
Mahmoudinia et al. (2020)	1980 - 2018	57 Islamic countries	Cointegration (Johansen) VEC	$p \Rightarrow^{+} y$
Sebikabu et al. (2020)	1974 - 2013	Rwanda	ARDL	Effect positive $(p \Rightarrow y)$

Notes: The table summarizes the results found in the literature review. In the results column, $y \Rightarrow p$ indicates a unidirectional causal relationship (Granger causality), where per capita income causes population, $p \Rightarrow y$ indicates population causes per capita income, and $p \Leftrightarrow y$ indicates a bidirectional causal relationship. The signs $+$ or $-$, and $(*)$, indicate the sign and significance when reported. Source: Authors' own elaboration.

Most of the studies reviewed focus on analyzing a specific country or group of countries individually, with a particular emphasis on populous developing countries. The limited number of studies using a panel approach tend to rely on a single criterion, such as population size (Sibe et al., 2016), (Rahman et al., 2017), economic bloc membership (Aksoy et al., 2019), or cultural attributes (Mahmoudinia et al., 2020). Using the same methodology, typically involving Granger causality and cointegration analysis, all possible results can be found. Some studies provide evidence of population driving economic growth (Darrat and Al-Yousif, 1999; Yao et al., 2007; Liu and Hu, 2013; Ali et al., 2013; Furuoka, 2013; Aksoy et al., 2019; Sebikabu et al., 2020), while for others it acts as a constraint (Li and Zhang, 2007; Yao et al., 2013). Additionally, there are studies showing bidirectional causal relationships (Furuoka, 2018), as well as cases where no causal relation is found, indicating that neither population causes nor is caused by economic growth (Dawson and Tiffin, 1998; Mulok et al., 2011).

Although there is an extensive body of literature, primarily focused on the most populous developing countries, the amount of research available for Mexico is relatively scarce. Despite this fact, the evidence is contradictory. Coale and Hover (1958) establishes a positive relationship for the period 1950-1975, while Kapuria-Foreman (1995) similarly discovers a unidirectional causal link, with population growth stimulating economic growth. Thornton (2001), however, does not find evidence of any causal relationship among the seven South American countries studied by him, including Mexico, spanning from 1921 to 1994. In this case, population growth neither causes nor is caused by economic growth, as per

Granger's sense. On the contrary, Garza-Rodriguez et al. (2016) provides evidence of a bidirectional causal relationship between the two variables.

To the best of our knowledge, our paper is the first to explore the connections between population and economic performance in Mexico using panel data. Although the 32 MS belong to the same country and therefore share the same history and institutions, among other distinctive features, their diverse development styles, geographical factors, and economic particularities have been influenced by distinct policies, resulting in varying demographic and performance dynamics within each region. This is why including the dynamics of all 32 MS in a single panel does not appear to be a suitable empirical strategy. To enhance the accuracy and validate our subsequent estimates more effectively, we initially conduct a cluster analysis. This enable us to divide the sample into homogeneous groups of states, so then we could perform the causality analysis for the entire sample and for each cluster separately.

3. Data and empiric approach

In the sample studied, we consider the dynamic behavior of the population and the per capita income observed in the 32 MS during the period from 1940 to 2020. Population data is obtained from Conapo[4] and per capita GDP from Germán-Soto (2005). In order to quantify the similarity of dynamic trajectories concerning these variables, we introduce the notion of distance between MS. For this, we initially locate each state in different regions within the state space based on observed dynamic behaviors. Afterwards, we code the data in order to obtain symbolic series that qualitatively represent the dynamics of each state in terms of population growth rate and economic performance. The symbolic series of each MS allow us to define a metric for comparing the dynamics among them, facilitating cluster analysis to form homogeneous groups.

3.1. Regimes and regime dynamics

By building upon Brida's work (Brida et al., 2011, 2013, 2021)[5], we introduced the concepts of "regime" and "regime dynamics" into our work. These concepts enable us to capture the most relevant qualitative properties related to the trajectories of each MS in terms of population and economic performance. A regime is a dynamic model where the state variables -in our case, population growth rate and GDP per capita level- exhibit particular behaviors that differentiate one regime from another. The basic concept is that each regime represents a unique qualitative relationship between the two variables. In our analysis, each regime is defined by partitioning the state space into four regions, delineated by the annual averages of each variable.

We establish two conditions: one for setting a threshold on annual population change and the other for determining a threshold on per capita GDP level. This led to the partition of the state space into the aforementioned four regions. Each one of them corresponds to a different relationship between demographic change and economic performance, therefore representing a distinct regime. By averaging the per capita income and population growth rate for all states during the analysis period, we obtain the

[4]Population database can be consulted in the Conapo web: https://www.gob.mx/conapo/acciones-y-programas/conciliacion-demografica-de-1950-a-2019-y-proyecciones-de-la-poblacion-de-mexico-y-de-las-entidades-federativas-2020-a-2070.

[5]In particular, the work of Brida et al. (2021) uses the same methodology to examine the causal relationship between growth and inequality using panel data for the 32 states of Mexico.

following partition of the state space:

$$R_1 = \{(p, y) : p \geq \mu_p, y \leq \mu_y\} \tag{1}$$

High rate of population growth coupled with low economic performance, characterized by a per capita GDP lower than the average. This is what we refer to as a *young economy regime.*

$$R_2 = \{(p, y) : p \geq \mu_p, y \geq \mu_y\} \tag{2}$$

High rate of population growth coupled with good economic performance, characterized by a per capita GDP above average. This is what we refer to as a *transition economy regime.*

$$R_3 = \{(p, y) : p \leq \mu_p, y \geq \mu_y\} \tag{3}$$

Slow population growth coupled with good economic performance, characterized by a per capita GDP higher than average. This is what we refer to as a *mature economy regime.*

$$R_4 = \{(p, y) : p \leq \mu_p, y \leq \mu_y\} \tag{4}$$

Slow population growth coupled with low economic performance, characterized by a per capita GDP lower than average. This is what we refer to as a *stagnant economy regime.*

As an example, Figures 1 and 2 show the values of population growth rate and per capita income for the 32 MS at the start and end of the analysis period. The lines indicate the average values defining the four regimes, with notable differences in these threshold values. At the beginning of the period, most MS are located between regimes R_2 and R_4, while at the end they are distributed among R_1, R_2 and R_4.

Different behaviors can be observed when analyzing the regimes visited by each state during the analysis period and the proportion of time spent in each of them, as shown in Table 2. The behavior of Guerrero, Oaxaca, San Luis Potosí and Zacatecas, which consistently remained in R_4 throughout the period (exhibiting high population growth rates and low performance), is completely distinct from the pattern followed by Baja California, Coahuila, Nuevo León or Ciudad de México that alternate between regimes R_2 and R_3 (high performance) or Chiapas, which alternate between R_1 and R_4 (low performance).

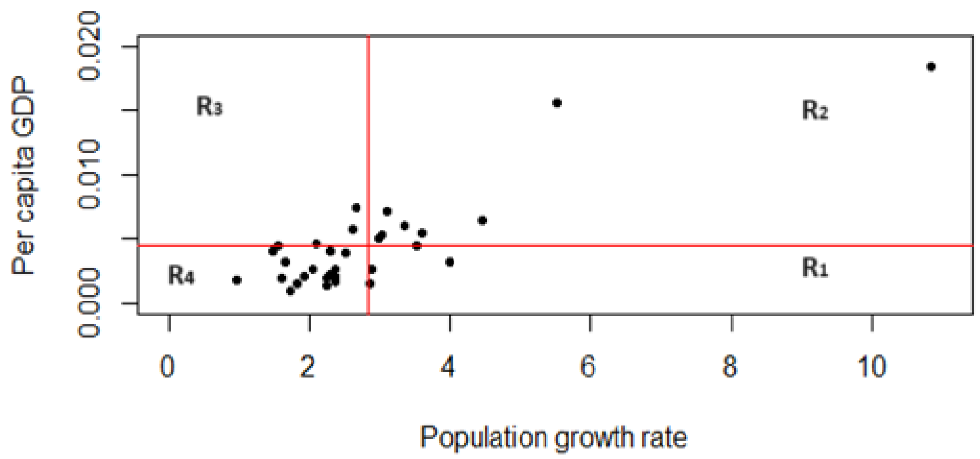


Figure 1: *Space of states, regimes, and cloud of points of the 32 MS at the beginning of the analysis period (1941)*

Notes: The partition is determined by the values μ_p and μ_y. The point cloud is defined by all MS in 1941. Source: Authors' own elaboration.

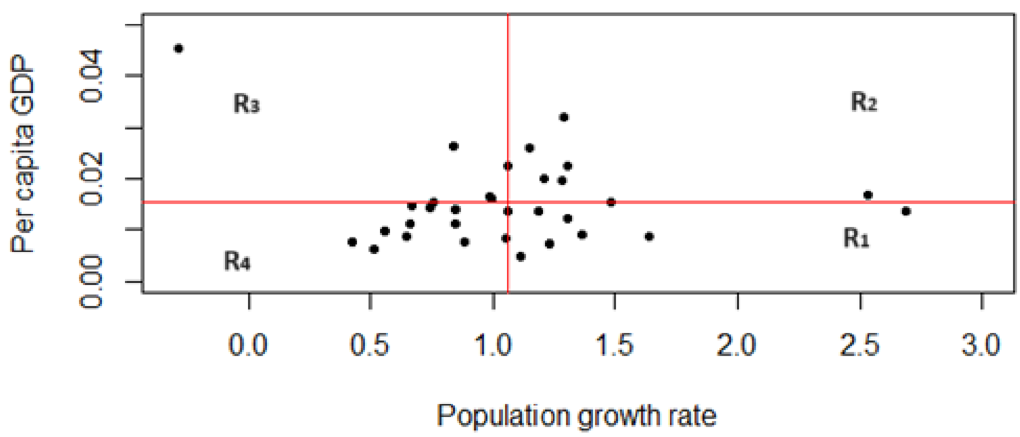


Figure 2: *Space of states, regimes, and cloud of points of the 32 MS at the end of the analysis period (2020)*

Notes: The partition is determined by the values μ_p and μ_y. The point cloud is defined by all MS in 2020. Source: Authors' own elaboration.

In the analysis of the regime shift dynamics, we follow the approach outlined in Brida et al. (2003), where each MS has assigned a label (1, 2, 3, or 4) based on its current regime at each moment in time. That is, we transform the bivariate time series $\{p_t, y_t\}_{t=1}^{t=80}$ of each MS into a symbolic series, $\{S_t\}_{t=1}^{t=80}$ where $S_t = j$ if and only if (p_t, y_t) belongs to region R_j in year t. This symbolic series summarizes the most relevant qualitative information on the dynamics of a MS's regime.[6]

As depicted in Figures 3, 4 and 5, a wide range of dynamic behaviors can be observed. In Aguascalientes, for example, the first 30 years show low population growth and low performance (R_4), fol-

[6]See Brida et al. (2003) and Brida and Punzo (2003) for a more detailed exposition of regime dynamics and its symbolic representation. In Brida et al. (2011) one can find an empirical analysis on convergence clubs that applies the same approach to that used in our paper.

Table 2: *Proportion of permanence in each regime within each MS, 1940-2020*

Code	Mexican states	R_1	R_2	R_3	R_4
A	Aguascalientes	26.25	36.25	1.25	36.25
B	Baja California	0.00	87.50	12.50	0.00
BS	Baja California Sur	3.75	71.25	20.00	5.00
CA	Campeche	42.50	32.50	25.00	0.00
CO	Coahuila	0.00	6.25	91.25	2.50
CL	Colima	47.50	27.50	20.00	5.00
C	Chiapas	56.25	0.00	0.00	43.75
CH	Chihuahua	0.00	38.75	56.25	5.00
CM	Ciudad de México	0.00	37.50	62.50	0.00
D	Durango	1.25	0.00	6.25	92.50
G	Guanajuato	18.75	0.00	0.00	81.25
GR	Guerrero	0.00	0.00	0.00	100.00
H	Hidalgo	11.25	0.00	0.00	88.75
J	Jalisco	12.50	0.00	43.75	43.75
M	México	40.00	22.50	0.00	37.50
MI	Michoacán	0.00	0.00	0.00	100.00
MO	Morelos	60.00	2.50	0.00	37.50
N	Nayarit	43.75	0.00	0.00	56.25
NL	Nuevo León	0.00	86.25	13.75	0.00
O	Oaxaca	0.00	0.00	0.00	100.00
P	Puebla	6.25	0.00	0.00	93.75
Q	Querétaro	21.25	40.00	2.50	36.25
QR	Quintana Roo	13.75	86.25	0.00	0.00
SL	San Luis Potosí	0.00	0.00	0.00	100.00
SI	Sinaloa	7.50	18.75	13.75	60.00
S	Sonora	0.00	68.75	28.75	2.50
T	Tabasco	45.00	11.25	8.75	35.00
TM	Tamaulipas	0.00	51.25	41.25	7.50
TX	Tlaxcala	42.50	0.00	0.00	57.50
V	Veracruz	3.75	8.75	21.25	66.25
Y	Yucatán	35.00	0.00	5.00	60.00
Z	Zacatecas	0.00	0.00	0.00	100.00

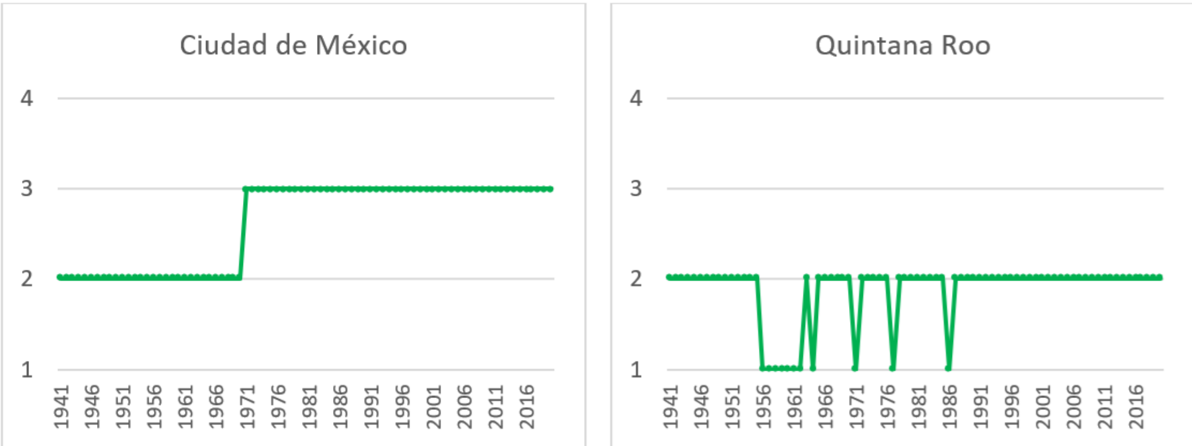
Source: Authors' own elaboration.

lowed by 20 years of above average population growth while maintaining low performance (R_1) ultimately transitioning to regime R_2 by the end of the period. Chiapas exhibits the opposite pattern. Throughout the entire period, it never enters regimes R_2 and R_3. Instead, it remains in low-performance regimes, with its population growth exceeding the average at the beginning and end of the period (R_1) but falling below the average between 1950 and 1980 (R_4).

In stark contrast, Ciudad de México falls into R_2 in the first third of the period, experiencing both a population growth rate higher than the average and maintaining a per capita GDP also higher than the average. However, for the remaining duration, it transitions to R3, maintaining consistently high economic performance while its population growth lags below the average.

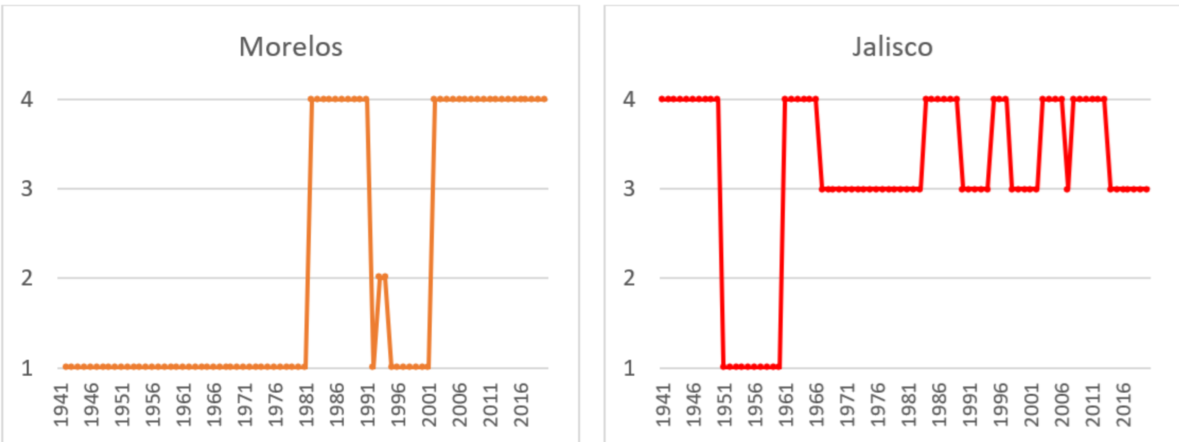
Source: Germán-Soto (2005, 2015) and authors' own calculations.

Figure 3: *Regimes dynamics for MS Aguascalientes and Chiapas, 1940-2020*



Source: Germán-Soto (2005, 2015) and authors' own calculations.

Figure 4: *Regimes dynamics for MS Ciudad de México and Quintana Roo, 1940-2020*



Source: Germán-Soto (2005, 2015) and authors' own calculations.

Figure 5: *Regimes dynamics for MS Morelos and Jalisco, 1940-2020*

Quintana Roo predominantly remains in the high performance and high population growth regime (R_2) throughout the period, briefly alternating with periods of low performance (R_1). Morelos exhibits a behavior more similar to that of Chiapas, remaining in the low-yield regimes (R_1 and R_4). However, its trajectory is distinguished by its high population growth rates in the first half of the period, followed by a decline in the second half. Meanwhile, Jalisco's behavior is somewhat more irregular, as it visits all regimes except for R_2.

3.2. Cluster analysis

To perform cluster analysis, we establish a distance metric to assess the proximity of MS regime dynamics represented by symbolic series, using the discrete distance, which is one of the most used measurements for symbolic time series.[7] We employ a metric supported by the notion that two MS regimes show greater similarity in their dynamics when they share more coincidences during the period of analysis. When dealing with regime dynamics represented as symbolic sequences, it becomes imperative to measure the distances between these symbolic sequences. Then, given two MS i and j with symbolic sequences $\{s_{it}\}_{t=1}^{t=T}$, $\{s_{jt}\}_{t=1}^{t=T}$ corresponding to MS i and j, we define the following distance:

$$d(i,j) = \sum_{t=1}^{80} f(s_{it}, s_{jt}), \text{with } f(s_{it}, s_{jt}) = \begin{cases} 0 & if \quad s_{it} = s_{jt} \\ 1 & if \quad s_{it} \neq s_{jt} \end{cases} \forall\, i \neq j, \forall\, t \tag{5}$$

Intuitively, the more coincidences two MS share in the same regime, the closer their distance becomes. When two MS exhibit an identical sequence of regimes, their distance reaches the minimum value of zero. The maximum distance, capped at 80, occurs when two MS never coincide within the same regime throughout any given year. After calculating the distances between the symbolic series of all the MS in the sample, we apply the MST and HT conglomerate technique to classify the states in our study.

To build the MST, we employ Kruskal's algorithm (Kruskal, 1956). In the first step, all distances were sorted in ascending order. This aggregate method starts from a tree of 32 nodes and no arcs and begins by connecting the two states closest to each other (smallest distance between them). It then moves to the second smallest distance and repeats this process until all distances have been considered. The outcome is a tree containing 32 nodes, each representing a MS data point, connected by 31 arcs that symbolize the distances between them. The resulting tree minimizes the total value of the distances among the nodes. Table 3 summarizes the most relevant distances. The MST makes it possible to illustrate the eventual formation of a cluster by pointing out the closest and most distant MS data points in their dynamics.

From the MST we elaborate the ultrametric distance (Mantegna, 1999) that allows us to analyze the degree of hierarchical organization among the graph's vertices, specifically in the context of the 32 Mexican states. The ultrametric distance $d^*(i,j)$ between MS i and j is defined as the maximum distance from node i to j through the shortest path connecting them at the MST. Thus, the MST allows the construction of the HT based on the ultrametric distance, as outlined by Mantegna and Stanley (1999) and Mantegna (1999), using the single link nearest neighbor algorithm.

To ascertain the ideal number of clusters, we use two statistical tests: pseudo-F (Caliński and Harabasz, 1974) and pseudo-t^2 (Duda and Hart, 1973). Both tests point to four as the optimal number of groups. Two of nearly identical size, with the remaining two clusters integrated by two states in one case and by only one in the other.

[7] We perform the same exercise using a distance concept that changes the weight regime, such as the one used in Brida et al. (2013), and the results did not change significantly.

Table 3: *Minimum spanning tree links in Mexican states*

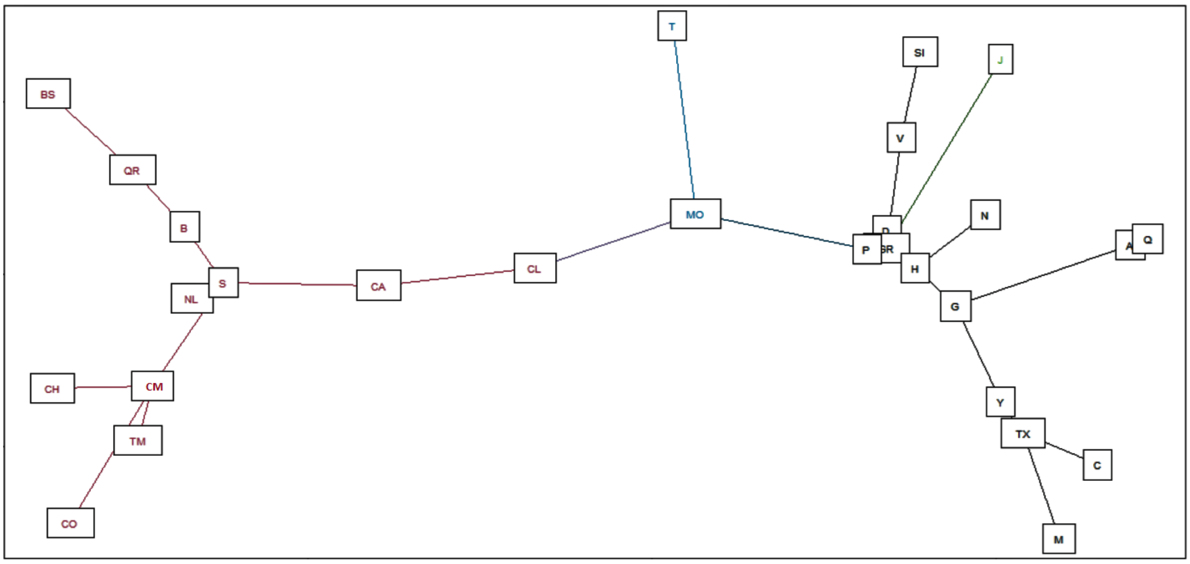
Step	MS_i	MS_j	Distance	Step	MS_i	MS_j	Distance
1	GR	MI	0	16	C	TX	21
2	MI	O	0	17	CH	CM	25
3	O	SL	0	18	N	H	26
4	SL	Z	0	19	S	CM	27
5	A	Q	5	20	V	GR	27
6	A	P	5	21	C	Y	27
7	D	GR	6	22	M	TX	28
8	H	GR	9	23	BS	QR	29
9	TX	Y	10	24	CO	CM	37
10	G	GR	14	25	MO	T	37
11	B	S	15	26	A	G	41
12	CM	TM	17	27	CA	S	41
13	NL	S	18	28	CL	CA	43
14	QR	S	19	29	CL	MO	45
15	SI	V	20	30	J	GR	45
				31	MO	P	45

Notes: After GR, MI, O, SL and Z, which pass through the same regime during the whole period, Q and P are the MS with the most similar regime dynamics. This table summarizes the most relevant distances in the construction of the MST. Source: Authors' own elaboration

Figures 6 and 7 depict the MST and HT derived from the previous exercise. Cluster 1 comprises the MS that predominantly experienced the R_1 and R_4 regimes throughout the analysis period, both characterized by low levels of GDP per capita. Within this cluster, Zacatecas, San Luis de Potosí, Oaxaca, Guerrero, and Michoacán collectively exhibit a consistent pattern, remaining persistently within the R4 regime, marked by low population growth and underperformance. Puebla, Durango, and Hidalgo also exhibit similar behavior but, notably, during the latter half of the period, they intermittently transition to $R:1$, accompanied by above average population growth. Completing this cluster are Guanajuato, Nayarit, Yucatán, Tlaxcala, Chiapas, Veracruz, Sinaloa, México, Querétaro, and Aguascalientes. In a general characterization, these states can be described as economically challenged, primarily located in the south-central and Gulf Coast regions (as shown in Figure 8, with these states depicted in purple on the map).

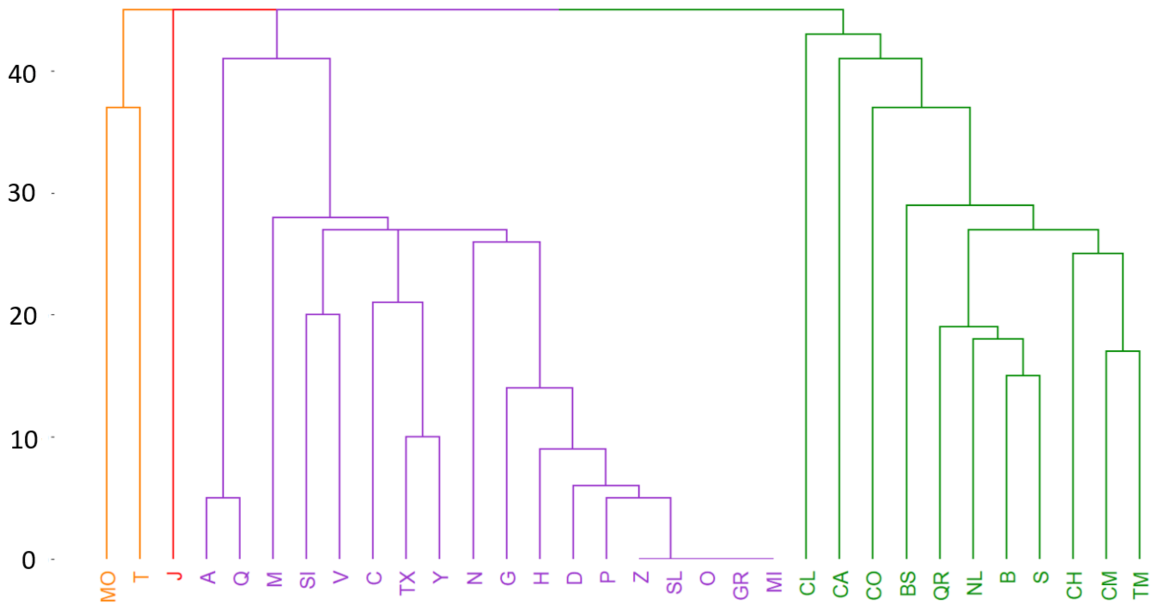
In Cluster 2, we find the Mexican states where above-average levels of GDP per capita have been observed, indicating the best economic performance. Most of these states are situated in the northern region, encompassing Baja California, Baja California Sur, Sonora, Chihuahua, Coahuila, Nuevo León, and Tamaulipas. These states have economies closely tied to the United States market. Additionally, the group includes Ciudad de México, Campeche, and Quintana Roo, which have exhibited significant and sustained dynamism in the tourism sector. Completing this cluster is Colima, which stands as the most geographically distant member from the others.

With regard to the dynamics of regime changes, cluster 1 shows less frequent changes. The MS at the core of this group tend to maintain the same regime throughout the period characterized by low population growth and poor performance. The states nearest to this central subgroup are those that shift to R_1, marked by high population growth, during the second half of the period while maintaining poor performance, and they continue to stay in this regime. In the case of cluster 2, which generally demonstrates good performance, there are more frequent transitions between regimes R_2 and R_3. An exception is Ciudad de México, which transitions to R_2 during the first half of the period and to R_3 during the second half. It is evident that the underlying model linking both variables in each cluster is not uniform.



Notes: Each MS is represented by a vertex in the MST. The vertices in black represent the MS that make up the first cluster. Please note the central position of Guerrero on the graph. While only Guerrero is labeled, it should be noted that it is equidistant from Zacatecas, San Luis Potosí, Oaxaca, and Michoacán, and they share the same position. The orange vertices represent those of cluster 2, and in blue (Morelos and Tabasco) and green the smaller groups, further away from the previous ones. Source: Authors' own elaboration.

Figure 6: *Minimum spanning tree in the Mexican states, 1940-2020*



Notes: In the hierarchical tree, two conglomerates of homogeneous MS (1940-2020) are identified based on their population behavior and economic performance. Cluster 1 (in purple) comprises 18 states, characterized by poor economic performance and primarily located in the central-southern region. Cluster 2 (in green) includes 11 states known for good economic performance, mainly situated in the northern regions. By analyzing the ultrametric distance at which the MS branch from the tree (on the y-axis), it is evident that the first cluster is the most homogeneous. The HT also reveals the presence of two smaller groups with dynamics that are more distinct from the rest. Source: Authors' own elaboration.

Figure 7: *Hierarchical tree in the Mexican states*

These differences, aside from being apparent in the potential functional forms, are also reflected in the varying rates and frequencies of regime changes.

To complete this stage of the analysis, we repeat the exercise considering population growth rates and per capita GDP growth (instead of the level). This is considered a partition of the state space defined by the means of both rates in each period. Applying the same methodology, we perform a cluster analysis. When classifying the MS based on the dynamics of changes in these new regimes, the obtained results were quite similar.

Notes: This map illustrates groupings within Mexico, which can be roughly divided into the North and Center-South regions. Source: Authors' own elaboration.

Figure 8: *Groups obtained on the Mexican map*

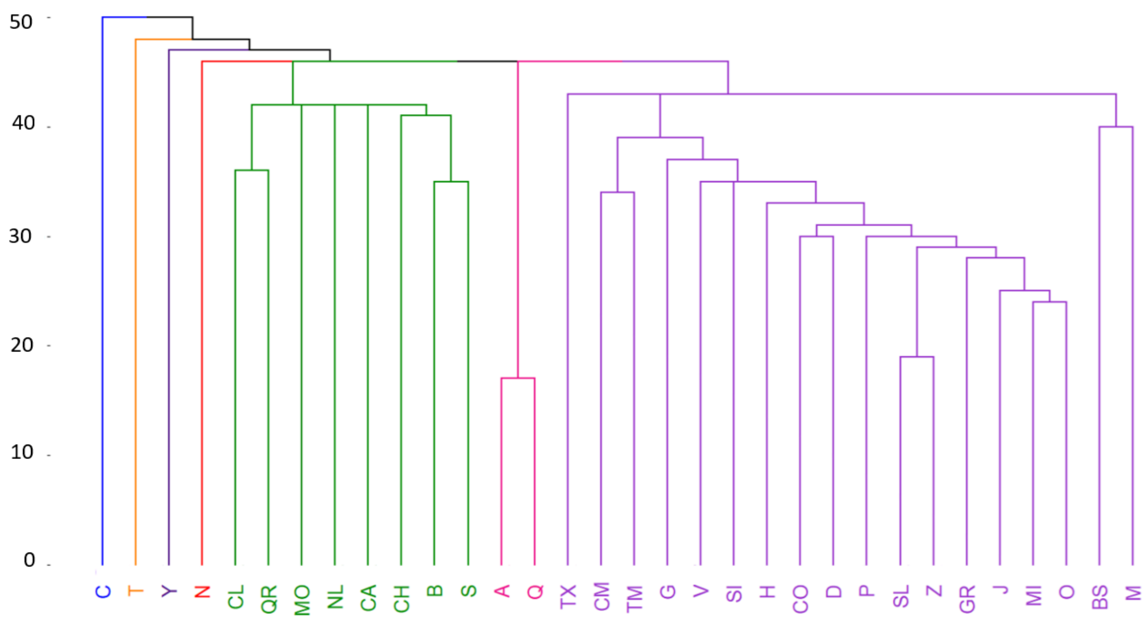
The states of Durango, Guanajuato, Guerrero, Hidalgo, México, Michoacán, Oaxaca, Puebla, San Luis Potosí, Sinaloa, Tlaxcala, Veracruz, and Zacatecas formed the same cluster as in the previous analysis. The second cluster comprises the states of Baja California, Campeche, Colima, Chihuahua, Nuevo León, Quintana Roo, and Sonora, just as it happened in the first analysis. In Table 4, the results and coincidences from both analyses are summarized. Figure 9 shows the HT resulting from this exercise. In general terms, the MS that are close as for behavior regarding population and per capita GDP evolution, also exhibit a similar behavior in relation to population growth and per capita GDP growth.

In summary, clusters are differentiated from each other by their behavior concerning population and economic performance (measured by the level and per capita GDP rates of growth). Our results are consistent with the findings of (Brida et al., 2013). In their study of regimes and performance groups in 32 Mexican states, the groups they call low and high performance are very similar to what we find. Our results seem to indicate that the links between population and economic growth also reflect the pronounced dual nature of the Mexican economy pointed out by the authors.

Table 4: *Cluster obtained from both exercises: levels and per capita GDP rates of growth*

Cluster	Levels (per capita GDP)	Rates of growth (per capita GDP)
1	A, C, **D**, **G**, **GR**, **H**, **M**, **MI**, N **O**, **P**, Q, **SL**, **SI**, **TX**, **V**, Y, **Z**	BS, CO, CM, **D**, **G**, **GR**, **H**, J, **M** **MI**, **O**, **P**, **SL**, **SI**, TM, **TX**, **V**, **Z**
2	**B**, BS, **CA**, CO, **CL**, **CH**, CM **NL**, **QR**, **S**, TM	**B**, **CA**, **CL**, **CH**, MO, **NL**, **QR**, **S**
3	M, T	A, Q
4	J	C, N, T, Y

Notes: overlaps between the two groupings in bold. Source: Authors' own elaboration.



Source: Authors' own elaboration.

Figure 9: *Hierarchical tree resulting from partitioning the state space into population and GDP per capita growth rates*

4. Panel causality, cointegration, and structural break

As established in the preceding sections, there is no consensus among different schools of thought, despite the strong correlation between both variables. It is nearly impossible to ignore the influence of population growth on per capita income. Now, we must explore the potential causality direction between these variables within the overall sample and within each of the previously identified clusters. To do this, we conduct Granger causality tests and VAR estimates for each sample. If causality is found, we also investigate the possibility of cointegration using the Johansen cointegration test.

Table 5 presents the main results on causality. Considering, as a preliminary approach, that variables homogeneously evolved over the period (all 32 MS), we apply causality tests for the entire duration. Noticeably, the results exhibit substantial variability. Granger causality tests for the overall sample suggest that per capita income influences population, but VAR point to bidirectional causality, as both variables are significant. Population is significant when the dependent variable is per capita income, and vice versa, the per capita income is significant when the dependent variable is population. Instead, for group 1, both estimation methods suggest bidirectional causality. There is also coincidence within groups 2 and 4, although in these clusters the conclusion is that per capita income influences population, mirroring the results observed in the overall sample. However, the most pronounced disagreement concerning causality is noted within the group 3. While Granger causality suggests a unidirectional relationship from per capita income to population, VAR estimates consider a bidirectional causality. Causality tests provide information about the direction of the effects, but cointegration tests inform us about the dynamic relationship between variables, indicating whether they evolve together over time. This is relevant because when cointegration is present, it suggests that the variables are closely interconnected. This, in turn, allows that variables can be used in regression models, with potential targets for policy interventions, and it is indicative that clusters are formed by homogeneous elements. Thus, evidence of cointegration is only demonstrated for the overall sample and groups 1 and 2. Groups 3 and 4 are not cointegrated according to the Johansen test.

However, it is possible that the results are affected by structural breaks due to the long-time frame of our series. If this is the case, it could introduce bias into our causality and cointegration tests, leading to different conclusions at each stage of analysis. To address this concern, we perform an endogenous identification of a single structural break. In the table 5, we separately consider causality and cointegration evidence for each stage identified by the structural break.

In brief, the identification of the breakpoint was performed using the Gregory and Hansen (Gregory and Hansen, 1996) test, which determines regime shifts in cointegration vectors. Models of regime shifts are based on the estimated residuals from specifications that model changes in the level of the series (L), trend (T), or both (S). Following the proposal by (Gregory and Hansen, 1996), the models are as follows:

$$Y_{i,t} = \mu_i + \theta_i DU_{i,t} + \beta_i T + \alpha_{i,1} X_t + \alpha_{i,2} X_t DU_{i,t} + u_{i,t} \tag{6}$$

where Y is, for our exercise, population growth, X is the per capita income rates of growth, DU is a dummy, and T is the linear trend. All the other terms are parameters to be estimated. In equation (6), if a structural change occurred solely in the level of the series (model L), then $\beta_i = \alpha_{i,2} = 0$. If the trend is also a relevant factor in the structural change (model T), then only $\alpha_{i,2} = 0$. Finally, if the structural change affected both the level and slope (model S), equation (6) is applicable. The choice of the best model is guided by the Bayesian Information Criterion (BIC).

The model in equation (6) operates as follows. Initially, an assumed time break (Tb) is selected, and $DU_{i,t}$ takes the value of 1 for $t > Tb$ and 0 otherwise. Subsequently, the order of integration of the residuals is determined by estimating equation (6) and applying the ADF test for unit roots, with critical values derived from the work of Gregory and Hansen (1996). Model (6) is calibrated for each potential time break until the residuals become stationary. The selection of the optimal breakpoint uses the BIC to identify the most suitable time break.

As shown in Table 6, the structural change defined by equation (6) was identified to have occurred in 1995 and 1997. Only group 2 exhibits a breakpoint, around 1997, albeit it is relatively close to the other samples. By applying the respective breakpoints to each sample, it becomes possible to estimate the causality between population growth and income for both the overall period and the specific stages determined by the estimated breakpoints. While the estimates from the Granger causality and VAR methods may yield different conclusions regarding causality in some cases, they converge at the same result for the second period. Following the structural change, the causality relationship disappears, as there is no evidence demonstrating the direction of causality from either technique. The absence of causality aligns with Thornton's findings (Thornton, 2001), which similarly reported no significant causality in Mexico during a different period, from 1921 to 1994.

In group 3, we observe a unique sample where the causality shifts from per capita income to population growth, despite the presence of bidirectional causality in the first period. For the other groups, as indicated by the VAR estimates, the results show that the overall sample and group 1 exhibited bidirectional causality over the entire global period.

Nevertheless, during the first period, the direction was different: both all sample and group 1 estimated causality from population growth to per capita income rates of growth, while group 2 maintained the same direction, from income to population. In contrast, group 4 estimated causality from population to per capita income for the entire period and during the stage before the breakpoint. It is worth noting that this group was classified as distinctly distant from the others.

An interesting avenue for investigation is the recent disappearance of causality. González-Rosas (2022) offers a possible explanation, highlighting the profound impact of Mexico's new population policy. This policy has achieved remarkable success in reducing fertility, achieving global recognition (Baca, 2007). According to said author, approximately 87% of this reduction can be attributed to the recent population policy. If this is indeed the case, it is possible that the weakening causality between income and population, as currently estimated, is a consequence of these recent developments. However, other factors, such as state migrations, are also possible explanations, so this assessment should be investigated further.

Table 7 presents cointegration estimates based on model L of equation (6), which was selected by the BIC criterion. The presence of a regime shift is significant in all samples, whether using the ADF or Zt statistics. Since the null hypothesis of no cointegration was rejected, implying that the residuals are stationary, it becomes possible to employ the t-statistics for valid inferences and to elucidate the dynamics of the population-income process in Mexican states. For instance, the consistently negative and significant estimation of the θ parameter across all samples suggests that, following the structural break, population growth was lower compared to the previous stage. This outcome aligns with the decreasing tendency observed in population growth rates. Similarly, the consistently negative and significant sign of the α parameter, although significant only at 10% for group 4, indicates that, on average, states with higher per capita income experienced lower population growth rates. This finding contrasts with the results of Garza-Rodriguez et al. (2016), where a bidirectional causality between per capita GDP and

Table 5: *Cluster causality and cointegration tests*

Granger causality (ADF-Fisher test)

All 32 states	Group 1	Group 2	Group 3	Group 4
Population does not cause income per capita				
1.690 (0.184)	33.517 (0.000)	0.744 (0.475)	2.017 (0.140)	0.489 (0.607)
Income per capita does not cause population				
4.728 (0.008)	14.412 (0.000)	3.071 (0.046)	4.372 (0.016)	4.178 (0.002)

Johansen cointegration test

All 32 states	Group 1	Group 2	Group 3	Group 4
None				
104.1 (0.001)	53.44 (0.030)	44.32 (0.003)	20.26 (0.137)	2.34 (0.716)
At most 1				
68.05 (0.341)	35.60 (0.487)	26.88 (0.216)	9.164 (0.169)	2.01 (0.732)

VAR

	Variable	Constant	Income per capita(-1)	Population(-1)	R^2
All 32 states	Income	0.000 (0.185)	0.977 (0.000)	0.0046 (0.034)	0.95
	Population	0.004 (0.000)	0.069 (0.001)	0.871 (0.000)	0.82
Group 1	Income	0.000 (0.141)	1.000 (0.000)	0.007 (0.000)	0.98
	Population	0.005 (0.000)	0.223 (0.000)	0.816 (0.000)	0.75
Group 2	Income	0.000 (0.000)	0.959 (0.000)	-0.005 (0.280)	0.92
	Population	0.004 (0.000)	-0.081 (0.014)	0.901 (0.000)	0.84
Group 3	Income	-0.000 (0.652)	1.000 (0.000)	0.014 (0.093)	0.99
	Population	0.011 (0.000)	-0.388 (0.005)	0.679 (0.000)	0.69
Group 4	Income	0.000 (0.190)	0.971 (0.000)	-0.004 (0.928)	0.95
	Population	0.012 (0.000)	0.186 (0.092)	0.711 (0.000)	0.76

Notes: ADF-Fisher unit root tests using two lags. P-values are in parentheses. The trace test is used in Johansen and one lag for the cointegration vector. For VAR regressions, the dependent variable in each cointegration equation is read by row.
Source: Authors' own estimates.

population was found. Group 2 stands out with the most substantial effect when compared to the other clusters. This group is characterized by strong economic performance of its states, which are located mainly in the northern region of Mexico.

Contrary to the results that not consider a regime shift, these findings present a stark contrast, especially when no evidence of cointegration can be demonstrated. This discrepancy implies that the inclusion of a single structural break in the model is essential for gaining a comprehensive understanding of the relationship between population and income, especially when approaching it from the perspective of clustering Mexican regions.

Table 6: *Results in cluster causality tests for the overall period and stages left by structural change*

	Breakpoint	Overall period	Before	After
Granger causality tests				
All sample	1995	GDPpc $\rightarrow$ POP	GDPpc $\leftarrow$ POP	None
Group 1	1995	GDPpc $\leftrightarrow$ POP	GDPpc $\leftarrow$ POP	None
Group 2	1997	GDPpc $\rightarrow$ POP	GDPpc $\rightarrow$ POP	None
Group 3	1995	GDPpc $\rightarrow$ POP	GDPpc $\leftarrow$ POP	GDPpc $\rightarrow$ POP
Group 4	1995	None	GDPpc $\leftarrow$ POP	None
VAR estimates				
All sample	1995	GDPpc $\leftrightarrow$ POP	GDPpc $\leftarrow$ POP	None
Group 1	1995	GDPpc $\leftrightarrow$ POP	GDPpc $\leftarrow$ POP	None
Group 2	1997	GDPpc $\rightarrow$ POP	GDPpc $\rightarrow$ POP	None
Group 3	1995	GDPpc $\rightarrow$ POP	GDPpc $\leftrightarrow$ POP	GDPpc $\rightarrow$ POP
Group 4	1995	GDPpc $\leftarrow$ POP	GDPpc $\leftarrow$ POP	None

Notes: GDPpc = gross domestic product per capita (rates of growth); POP = rates of population growth; None = none causality evidence. One lag is used for the VAR estimates. The symbols $\rightarrow$ and $\leftarrow$ indicate causality in one direction, while $\leftrightarrow$ indicates bidirectional causality. Source: Authors' own elaboration

Table 7: *Results of cointegration with regime shift*

Cluster	Breakpoint	ADF_GH	$Z_t - GH$	$\hat{\mu}$	$\hat{\theta}$	$\hat{\alpha}$
All sample	1995	-6.285*	-6.322*	0.039*	-0.006*	-1.142*
				(19.47)	(-2.51)	(-6.101)
Group 1	1995	-5.666*	-5.596 *	0.028*	-0.005*	-0.782*
				(14.92)	(-2.24)	(-3.10)
Group 2	1997	-7.930*	-7.981*	0.057*	-0.005*	-1.472*
				(28.39)	(-2.51)	(-11.73)
Group 3	1995	-5.205*	-5.196*	0.033*	-0.004	-0.916*
				(18.27)	(-1.86)	(-5.46)
Group 4	1995	-5.231*	-5.132*	0.036*	-0.017*	-0.405
				(13.40)	(-5.152)	(-1.64)

Notes: ADF_GH and $Z_t - GH$ denote Gregory-Hansen cointegration statistics. t-statistic in parentheses. Superscript * stands for rejection of the null hypothesis of non-cointegration at 1% level of significance. All estimates are for the level of the series, model L selection based on the BIC information criterion. Source: Authors' own elaboration.

5. Concluding remarks

This research paper contributes to the empirical literature that explores the complex relationship between population and economic performance in several ways. First, it focuses on the case of Mexico, an economy ranked 10th in the ranking of the most populous countries. The analysis is based on disaggregated data for each of Mexico's 32 states during a long period. The empirical strategy was carried out in two stages, using novel techniques in each one. The first stage, which involved exploratory analysis without assuming any hypotheses and utilized non-parametric methods, allowed us to create homogeneous groups of MS. These groups consist of MS exhibiting similar dynamic trajectories regarding population growth and economic performance during the analysis period while also distinguishing between different groups. Prior to the cluster analysis, we introduced the concept of "regime", which allowed us to transform the bivariate series of population growth and economic performance into one-dimensional symbolic series. These symbolic series retained the most pertinent qualitative information regarding the dynamics of each individual MS.

We observe two major state groups and two smaller ones. The first group made up of 18 states with poor economic performance, below-average population growth in the first half of the analysis period, and a location primarily in the central and southern regions of the country. The second group comprises 11 states, mainly situated in the northern part of the country, with strong economic performance. Creating these homogeneous groups based on objective criteria derived from the data itself permitted a more efficient application of a panel Granger causality analysis within each group.

In the second stage, we estimate econometric models for each MS group and the entire sample. Subsequently, we conduct Granger causality analysis and cointegration tests for these econometric models. Additionally, we explore these hypotheses while considering a potential change in the relationship at a specific point in time.

For the entire sample, Granger causality tests concluded that per capita income rates of growth impact on population, while VAR estimates suggest bidirectional causality. In Group 1 (poorer states), both estimation techniques arrive at the same result of bidirectional causality. Regarding groups 2 (wealthier states) and 4 (Morelos and Tabasco), both techniques arrive at the conclusion that income per capita causes population growth, as in the overall sample. On the other hand, there is a notable divergence in the conclusions for Group 3 (Jalisco). Granger causality estimates a unidirectional relationship from income per capita to population, whereas VAR estimates point to bidirectional causality.

While causality tests provide insights into direction of the effects, cointegration tests inform us about the dynamics between variables. Cointegration evidence is only observed for the entire sample and groups 1 and 2. However, groups 3 and 4 do not exhibit cointegration, as determined by the Johansen test. Given the lengthy span of our data series (80 years), the possibility of a structural break was considered. Causality and cointegration tests may be biased by this circumstance, which may lead to different conclusions at each stage. We found evidence of a structural change occurring between 1995 and 1997 across the entire sample and all four clusters. After this structural change, the causality relationship disappeared, as neither technique provided evidence of the direction of causality. Results indicate that the overall sample and group 1 showed bidirectional causality over the entire period. Nonetheless, in the first period, the direction was different; both estimated causality from population to income. In contrast, group 2 maintained the same direction, from income to population.

In the Mexican experience, a prevailing causality relationship exists between population and per capita income (as rates of growth), with the direction typically from the latter to the former. However, the causality direction changes in response to structural breaks occurred over time and align with the homogeneous groups identified as clusters. While various methods identify similar change points, causality weakened after the estimated structural break. This discovery aligns with suggestions from the unit root literature, which indicates that structural breaks tend to alter the nature of the relationship between two variables being compared. Furthermore, these results make a valuable contribution to the literature on how a single structural break can impact causality and cointegration relationship.

The results for Mexico confirm the challenges of creating a unique model to explain the intricate relationship between population and economic performance. The cluster analysis and subsequent causality-cointegration analysis suggests that the data-generating processes (and underlying models) in each of the identified clusters are qualitatively distinct from one another.

Future research will delve deeper into several areas. Incorporating other factors, such as state migration, would be helpful for a more comprehensive understanding of the phenomenon. Finally, the inclusion of relevant variables like physical and human capital, along with demographic factors such as fertility, would also contribute to a more comprehensive analysis.

6. Acknowledgments

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