The Business-Cycle and Its Relationship with Electricity Consumption and Temperatures in Mexico

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Abstract

This research addresses the co-movement, persistence, and volatility of the business-cycle, electricity consumption, and temperatures in Mexico during 2002.1-2019.4. Theoretically, electricity consumption sustains a direct but non-linear relationship with economic development and temperatures as it is affected by seasonal factors. The greater the volume of economic activity, the greater the demand for electrical energy. Also, the extreme weather raises demand for electricity. For the extreme weather seasons (winter and summer), consumption is accentuated due to the greater fluctuation of the electricity supply. The cyclical components, obtained from the X-13 ARIMA technique, are used to analyze the co-movement, volatility, and persistence. Findings suggest that electricity consumption is pro-cyclic to the business-cycle, but maximum and minimum temperatures are countercyclical, while the link between minimum temperature and business-cycle shows the greater volatility, so extremely cold climates are a greater risk factor than hot climates, with substantial effects on economic development and electricity consumption. Persistence (duration of fluctuations) is not significant, a result related to seasonality of the temperatures. Conclusions suggest some policy recommendations to address future electricity demand.

Keywords: Cyclical properties, Volatility, Co-movement, Seasonal series, Serial correlation

1. Introduction

Electricity is an essential resource that has historically accompanied the technological and economic development of countries and has also been a precursor to improving social welfare. Modern lifestyles have made it necessary to use electricity for almost every human activity, resulting in electricity costs becoming a substantial portion of household, business, and public sector budgets.

It has been observed that electricity consumption in Mexico has experienced sustained growth, likely related to economic development, the increase in the number of users, and climate-related factors such as rising temperatures caused by phenomena such as climate variability and change. It is essential to understand the behavior of electricity consumption to improve economic performance, as it is not only an essential resource for human and industrial activity, but also crucial for driving economic development in countries and regions. As electricity consumption increases, a higher percentage of the budget is allocated to the electricity sector, reducing the available budget for other economic sectors with serious implications for economic development.

Kotz, Wenz, Stechemes, Kalkuhl, and Levermann (2021) concluded that the impact of temperature on economic development can exacerbate economic and social disparities, promoting inequality. A reliable and robust electricity supply is essential for promoting and enhancing regional and national economic development. In contrast, the inadequacy of this resource can hinder a country's development and increase social and economic inequalities.

Contemporary societies make increasingly intensive use of electricity to improve their levels of economic development, but improvements in economic development also demand greater use of electricity. However, this relationship is also affected by temperature, such that extreme temperature changes result in more intensive electricity use. In this regard, some interesting questions are, for example, which of the two temperatures, the maximum or the minimum, is more demanding on electricity? How much does economic development influence the increase in electricity consumption?

The objectives of this research are to analyze the national-level temporal evolution of the relationship between development, electricity, and temperature, as the literature suggests that climatic variables such as temperature are often underestimated predictors in electricity sector planning (Mukherjee and Nateghi, 2018).

The Real Business Cycle methodology is used to obtain the cyclical properties of time series for economic development, electricity, and temperature to test the idea that fluctuations, persistence, and volatility in electricity supply are conditioned by changes in temperature and economic development. One of the main findings is that the relationship between electricity, economic development, and temperature is becoming increasingly intense over time due to the increase in variation of extreme temperatures.

This work is organized in five sections. After de Introduction section, firstly, a review of literature on the connection between the core of variables is presented, after that, the section three exposes the method to estimate the cycle, the database, and some exploratory analysis. Section fourth describes the results and, finally, section fifth concludes.

2. Business cycle, electricity consumption, and temperatures: a review of the literature

The electricity is a good with a transversal impact on all economic sectors, thus affecting the economic cycle of countries and regions. Temperatures also directly and indirectly impact the economic cycle, directly affecting the productivity of the means of production and indirectly through electricity consumption given an increase in thermal fluctuations. On this last relationship, authors such as Franco and Sanstad (2008), Fung, Lam, Hung, Pang and Lee (2006), and Wouter Botzen (2020) found non-linear relationships between electricity consumption and temperature, all researches coincide in a U-shaped asymmetric relationship between electricity and temperature.

Particularly in the electricity-economic development relationship, higher electricity consumption is associated with higher levels of economic development, and higher levels of economic development are related to increases in electricity consumption. Yoo and Kwak (2009) and Wolde-Rufael (2006) find that the relationship between electricity consumption and economic development varies between countries. Yoo et al. (2009) investigate this relationship in seven South American countries such as Argentina, Brazil, Chile, Colombia, Ecuador, Peru, and Venezuela for the period 1975-2006. The authors perform Granger causality tests and detect a short-term unidirectional causality between electricity consumption and real GDP for Argentina, Brazil, Chile, Colombia, and Ecuador. However, in Venezuela, there is a bidirectional causality between electricity consumption and economic growth, which could represent a feedback effect between both variables.

Gómez and Rodríguez (2015) investigate the case of Mexico in the relationship between electricity consumption and economic growth for the period 1971-2011. The results show a causal relationship between economic growth and energy consumption, proving the conservation hypothesis. Therefore, an important conclusion is that energy policies have little or no impact on national economic growth.

Authors such as Wolde-Rufael (2006), Yoo (2009), and Karanfil and Li (2015), although using different country groups and periods, coincide that the electricity consumption-growth nexus depends deeply on regional differences and levels of economic growth. Wolden-Rufael (2006) refers to levels of electrification, Yoo et al. (2009) to industrial structures, and Karanfil et al. (2015) refer that the electricity-growth nexus is sensitive to income levels, urbanization, and the level of electricity dependence. In this regard, it is highlighted as a conclusion that rich economies present a low causality and short-term relationship between growth and electricity consumption, while in poor economies, the causal relationship is long-term and high.

Regarding the direct effects of temperature on the economic cycle, Dell, Jones, and Olken (2012), Kalkuhl and Wenz (2020), Kotz, Wenz, Stechemes, Kalkuhl, and Levermann (2021) agree that temperature has a more intense negative effect on poor countries. Although each research analyzed different regions and periods, this conclusion remains in each one of them. However, Dell et al. (2012) and Kotz et al. (2020) extend observations by estimating the effect of a 1°C increase in temperature on economic growth, where for Dell et al. (2012), it represents a reduction in economic growth of 1.4%. For Kotz et al. (2021), a 0.2°C increase in daily temperature would have a negative impact of 1% on economic growth. Although the authors do not use the same variable, it can be observed that the magnitude of the impacts of temperature on economic systems is important since they are comparable to the average size of the effect of GDP volatility on national growth rates (Kotz et al., 2021).

Regarding the increasingly important influence of temperature on electricity consumption, research conducted by Sailor (1997) and Staffell, Iain, Pfenninger and Stefan (2017) agree that temperature variability has been increasing over time and is becoming a factor with a growing impact on electricity consumption. Additionally, Staffell et al. (2017) associate the concept of climate variability with risk, which is essential for establishing practical use of the knowledge obtained in terms of informed decision-making on energy planning and policy. Several studies analyzing the relationship between development, electricity, and temperature, such as those by Boukhelkhal and Bengana (2018), Sailor (1997), Mukherjee et al. (2018), and Hor, Watson, Majithia and Shanti (2005), conclude that temperature is the most influential weather factor in electricity consumption. Furthermore, they determine that there is a strong correlation between the growth of electricity consumption and GDP, as well as with the growth of electricity demand and population. In a dynamic climate context, ensuring a reliable supply of electricity is essential, as a robust energy system in a country provides strength and security in the path of economic development.

The use of the business cycle methodology allows for the analysis of fluctuations and co-movements of variables over time to identify short- and long-term trends. Therefore, the applicability of the knowledge of the economic cycle and its relationship with electricity consumption and temperature cycles allows for adequate design and generation of public policies in energy and economic development.

3. Methods and data

3.1. The X-13 ARIMA

Census X-13 is a time-series seasonal adjustment software developed by the U.S. Census Bureau. The software is used to remove seasonal patterns in time-series data, allowing for more accurate analysis and forecasting. The methodology used by Census X-13 is based on the well-established X-11 method, but with additional features and improvements to handle more complex data.

One of the main advantages of Census X-13 is its ability to handle multiple seasonal patterns and outlier detection. The software can identify and remove different types of seasonal patterns, such as day-of-the-week effects, holiday effects, and trading day effects. Additionally, it can detect and adjust for outliers in the data, which can improve the accuracy of the adjustment. Another advantage of Census X-13 is its user-friendly interface and the ability to automate the adjustment process, saving time and increasing efficiency.

However, there are some limitations to Census X-13. One limitation is that the software requires a significant amount of data to produce accurate adjustments. The software may not perform well on small data sets, leading to inaccurate seasonal adjustment. Another limitation is that the software assumes a stationary time-series, which may not always be the case in real-world data. This assumption can lead to inaccurate adjustments in non-stationary time-series data.

Despite its limitations, Census X-13 is widely used in academia, industry, and government agencies for seasonal adjustment. The software has been used in research studies to investigate the effects of seasonality on economic indicators such as employment, production, and sales.

The Census X-13 filter, as well as its predecessors X-11, X-12, are based on ARIMA methodology, which is a statistical method used to model time series. It is based on decomposing time series into the autoregressive (AR), integrated (I), and moving average (MA) components. This methodology is used to predict the future values of a given time series based on past values. If a time series is stationary and has a decreasing autocorrelation function, it is analyzed using a suitable ARMA process to represent the corrected data. If not, a transformation of the data is sought to generate a new series with the properties (stationary and decreasing autocorrelation), which is achieved through differencing, leading to the use of the class of ARIMA processes (Brockwell and Davis, 1991). The methodology starts with the idea that time series have seasonal patterns and other factors that affect their behavior over time. The goal of the Census X-13 filter is to separate these patterns from the underlying data, providing a more accurate and detailed picture of the data's behavior. Throughout the process, different adjustments and corrections are applied to remove seasonal, calendar, and other factors that may affect the accuracy of the analysis.

3.2. Data and variables

The database is integrated by quarterly time series of the variables, economic development, electricity sales, and temperatures for the period 2003.I-2019.IV. Regarding the Electricity Consumption variable, data on electricity sales were used, obtained from the Energy Information System of the Ministry of Energy, as well as data collected from annual reports of the Federal Electricity Commission. The reported units are Mega Watt-hours (MWh). For the Temperature variable, both maximum and minimum temperature series were obtained. The information was obtained from reports from the National Meteorological System, and the reported units are in degrees Celsius (°C).

As a measure of economic development, the Quarterly State Economic Activity Indicator (ITAEE) with a 2013 base year, obtained from the INEGI website, is considered. The ITAEE is a quarterly indicator that provides short-term information on the economic development.

Table 1 shows an exploratory analysis of the data in its original form. It is evident that the coefficient of variation between economic development and electricity sales is near 0.11 and 0.12, respectively. This means that the proportion between the standard deviation of each variable and its mean is relatively similar for both variables, and overall, the variability of both variables is comparable. Additionally, the minimum temperatures exhibit the highest coefficient of variation, more than double that of the other variables, while the maximum temperature has the lowest coefficient of variation. Therefore, the minimum temperatures have experienced the greatest variation throughout the period.

Table 1. Descriptive statistics of the variables.

	Economic development	Electricity sales	Maximum temperature	Minimum temperature
Mean	96.988	48.613	29.235	14.371
Standard deviation	10.457	6.201	2.753	3.521
Coefficient of variation	0.108	0.128	0.094	0.245
Maximum	115.600	62.800	33.067	19.570
Minimum	78.930	37.590	23.533	8.430
Kurtosis	1.837	2.347	1.404	1.518
Skewness	0.158	0.274	-0.016	0.041

Notes: Electricity sales are in millions of megawatt hours and temperatures are degrees Celsius.

Upon examining kurtosis, the electricity consumption variable stands out with a value of 2.34, indicating that, in comparison to the other variables, its distribution has a higher concentration of values in the central region and a heavier tail, indicating that extreme values of the variable are more frequent.

There is no specific superior limit for kurtosis, as it can vary depending on the dataset being analyzed. However, generally, a distribution is considered to have high kurtosis if its coefficient of kurtosis is above 3 or 4, which is not the case for economic development. It is important to note that a distribution with high kurtosis does not necessarily indicate an abnormal or incorrect distribution, but simply that it has a different shape from that of a standard normal distribution.

For the case of economic development, maximum and minimum temperatures, kurtosis would indicate the shape of the distribution of each variable. These variables have kurtosis in the range of 1.4 to 1.8, which can be said to have moderately to highly pointed distributions, meaning they have relatively heavy tails and are slightly sharper than the normal distribution.

Regarding skewness, the highest values for electricity consumption and the index of economic development are 0.27 and 0.16, respectively, which would indicate an asymmetry in the distribution of data, with extreme values towards the right side of the average. Relatively small values are exhibited in skewness for the maximum and minimum temperatures, indicating very slight biases in the distribution of both variables, that is, they are practically symmetrical. It is shown that at the national level, the highest value for skewness is presented by electricity consumption.

There is also only one negative value, albeit small (-0.016) for the skewness of the maximum temperature. This means that the distribution of data for this variable is slightly skewed to the left of the mean, suggesting that there are more extreme values on the left side of the distribution. However, the skewness is relatively small indicating that the distribution is almost symmetrical.

Just as kurtosis and skewness provide information about the shape of the data distribution, trend indicates long-term behavior (Figure 1). National-level trends in the variables of economic development, electricity consumption, and temperature show a generally increasing behavior. It can be observed that the growth of electricity consumption is slightly more rapid than that experienced by economic development.

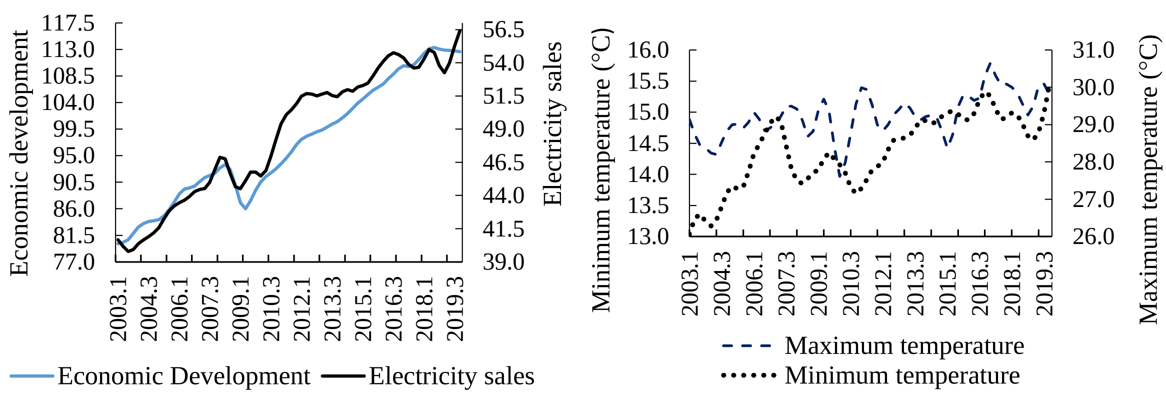

Figure 1. The trend component of the variables, 2002.I-2019.IV.

On the right-hand side of the Figure 1, the trend of maximum and minimum temperatures is observed. The minimum temperature shows a growing trend with greater intensity than the maximum temperature. Although in recent years, the trends of both temperatures (maximum and minimum) show similarity. Consequently, there are non-seasonal oscillations in the temperature series, possibly due to some other anthropogenic factors.

4. Results and discussion

Following the Real Business Cycle theory and using the Census X-13 filter, the cycle of each variable is obtained and their properties such as volatility, co-movement, and persistence are analyzed.

In Table 2 the volatility of minimum temperatures is higher than the volatilities of electricity sales and maximum temperatures. This result is much clearer when examining the relative volatility of each variable in relation to the economic development. Series of minimum temperatures exhibited a volatility 14 times greater than that of economic development along the period, while it was between 2 and 3 times with electricity sales and maximum temperatures, respectively. This result suggests that in Mexico, minimum temperatures show greater cyclical amplitude than economic activity. As volatility is related to dispersion and variance, it can be inferred that minimum temperatures are a greater risk factor for economic development and electricity sales.

Table 2. Cyclical properties and relations with business cycle, 2002.I-2019.IV.

Variable	Volatility	Relative volatility	Co-movement		Persistence
Economic development	0.017	1.00	1.000		-0.768 (0.000)
Electricity sales	0.071	4.18	0.101	[pro-cyclical]	-0.014 (0.904)
Maximum temperature	0.090	5.31	0.065	[pro-cyclical]	-0.030 (0.801)
Minimum temperature	0.237	13.97	0.058	[pro-cyclical]	-0.011 (0.924)

Note: the p-value of the estimated autocorrelation for persistence is reported in parentheses.

When observing the co-movement, both temperature series show a counter-cyclical behavior, although very close to zero. The degree of proximity to zero may reflect that extreme temperatures do not have to do with the economic cycle, since they obviously obey more climatic than economic reasons, but also, when analyzing extreme temperatures in the national format, resolution is lost about temperature behavior and its relationship with the economic cycle. These reasons explain the counter-cyclical and close-to-zero nature of co-movement.

As expected, electricity sales are procyclical since electricity demand can be linked to the level of economic development. If the economy is doing well, consumers improve their income and, consequently, increase their spending on electricity; but if the economy is doing poorly, income is affected and they have to compensate with reductions in electricity consumption. In summary, electricity sales are procyclical.

Regarding the cyclical property of persistence, the estimated value is negative in all variables, but it is only significant for economic development. There are at least two comments on this result. First, the fluctuations of the electricity sales and temperature cycle tend to be short-lived, not very high, and tend to constantly change from high to low values and vice versa. Comparatively, economic activity presents longer duration fluctuations, while its negative value –and in absolute terms, high– is a signal that during the period studied economic growth has not been continuous or homogeneous, since it alternates between high and low values. This conduct also reflects the level of uncertainty characterizing the economic activity continuously affected by crises, expansions, contractions, slowdown of the growth, etc., while temperatures and electricity consumption experience softer changes.

One hypothesis of this research is that the increase in temperatures may be correlated with the demand for electricity, in the sense that, as extreme temperatures worsen, there is a greater demand for electricity use. Therefore, the cyclical behaviors of temperatures and electricity demand should also be compared (Table 3).

Table 3. Cyclical properties and relations with electricity sales cycle, 2002.I-2019.IV.

Variable	Volatility	Relative Volatility	Co-movement		Persistence
Electricity sales	0.071	1.000	1.000		-0.014 (0.904)
Maximum temperature	0.090	1.268	0.839	[pro-cyclical]	-0.030 (0.801)
Minimum temperature	0.237	3.340	0.964	[pro-cyclical]	-0.011 (0.924)

Note: the p-value of the estimated autocorrelation for persistence is reported in parentheses.

In Table 3 temperatures exhibit a procyclical behavior with electricity sales, confirming the hypothesis that both temperatures and electricity sales tend to follow each other, although the co-movement degree of the minimum temperatures is relatively higher than that of maximum temperatures. The same observation holds true for volatility and relative volatility. This means that minimum temperatures are the most significant factor contributing to electricity consumption in the country. This finding has important public policy implications, for instance, knowledge that the cycle of minimum temperatures is more related to electricity sales allows for anticipation of higher electricity demand in certain seasons and may help prevent possible electricity shortages. Since Mexico has regions with more intense climate than other regions, this could also help understand where there will be higher electricity demand and generate public policies that integrate appropriate strategic plans for each climate, region, and season. Given the natural seasonal behavior of temperature series and the seasonality observed in electricity sales and economic development series, it is convenient to analyze the cyclical evolution of variables over the period to recognize cyclical properties such as volatility and co-movement and establish useful comparisons to support analysis (Figure 2).

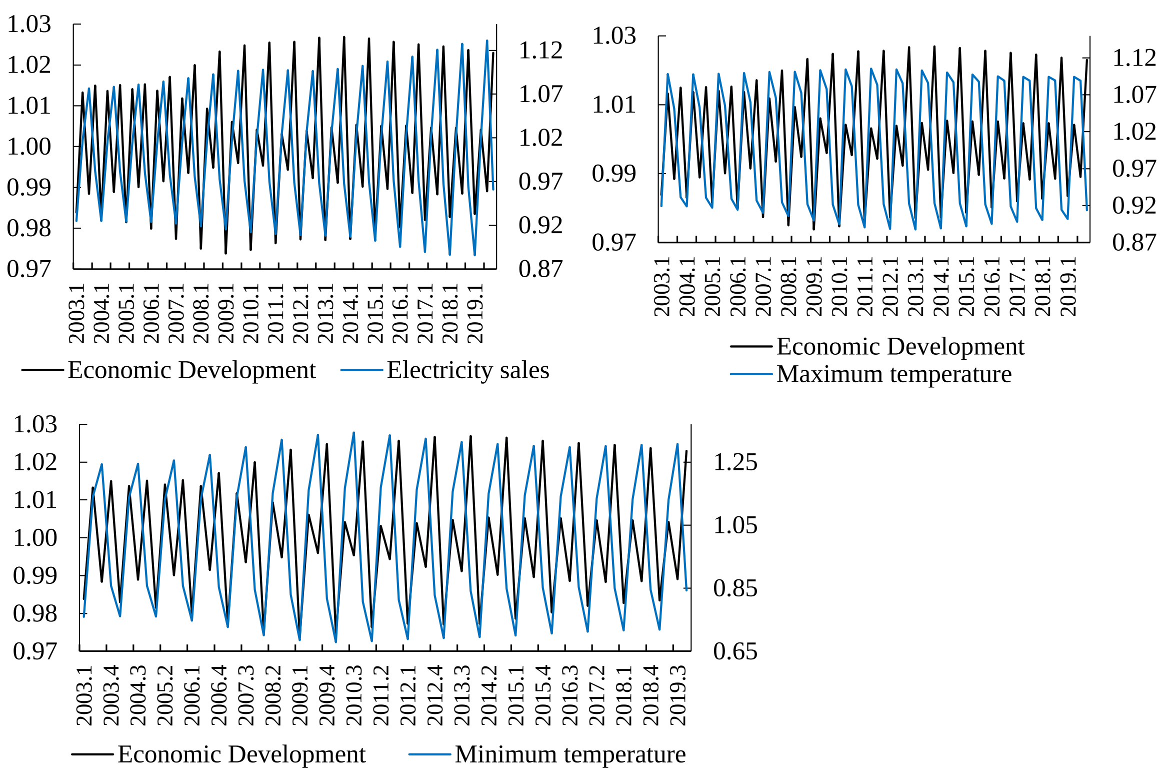

Figure 2. Cyclical components: comparisons with economic development, 2003.I-2019.IV.

Electricity sales in Figure 2 show a sustained increase in cycle amplitudes throughout the period, which is indicative of an increase in volatility and so a gradual increase in the risk of this variable, confirming the hypothesis about an increasing risk in electricity consumption over time. This result may be related to the volatility of minimum temperature since comparing the cyclical evolution of economic development, electricity sales, and temperatures, a greater cyclical amplitude is observed for minimum temperature. A public policy and adequate planning of the electricity supply must consider that the minimum temperature is a higher-risk element that significantly impacts electricity consumption.

As this work proposes, an increase in temperature variability implies greater electricity demand, so it is convenient to compare the cyclical evolution of these variables (Figure 3). The cyclical evolution of electricity sales with both maximum and minimum temperature is procyclical, coinciding with the results in Table 3. This confirms the hypothesis that the greater variation in temperature, the greater the electricity consumption.

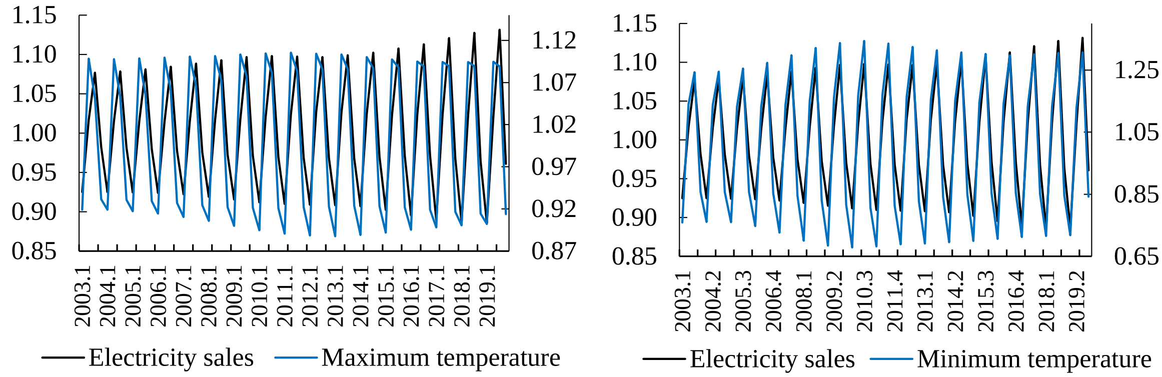

Figure 3. Cyclical components: comparisons with electricity sales, 2002.I-2019.IV.

Based on the previous results, in Mexico the cycle of minimum temperatures exhibits a greater level of correlation with electricity sales and economic activity compared to the cycle of maximum temperatures. Therefore, variations in minimum temperatures are a higher-risk factor that significantly impacts electricity consumption.

5. Concluding remarks

The prominent role of the volatility in minimum temperatures is evident and should be of consideration in the planning of the electricity sector. Due to this property, dispersion in minimum temperatures is high and it represents a risk factor elevating the electricity consumption and impacting the economic development. In the Mexican experience, there is no correlation between the cycle of the economic activity and the cycle of the temperature. There are at least two possible explanations. The first is that temperature fluctuations are independent from the economic activity, as is expected. Temperature fluctuations are more influenced by climatic conditions than economic factors. Secondly, national temperatures are averages of all states in the country, resulting in a loss of resolution in the economic development-temperature relationship. Nevertheless, this result also highlights the importance of monitoring extreme temperatures in making public policy decisions in the economic and energy fields.

On the other hand, there is a correlation between electricity consumption and economic activity. The more developed an economy is, the more disposable income and electricity consumption will increase. Similarly, if the country reduces its economic activity, both income and electricity consumption will decrease. This indicates that a robust and reliable National Electric System is a determining driver for Mexico's economic development, but deficiencies in the electricity supply will negatively impact the country's economic development. Overall, the research provides valuable information for decision-makers who seek to design effective evidence-based public policies to address the climate and economic challenges in the country.

Additional lines of research suggest investigating the cyclical properties in the Mexican regional context. This line will provide valuable information due to the great heterogeneity of climates and the persistent economic inequality that prevails among the Mexican states.

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