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UNHEALTHY GROWTH? THE NEXUS BETWEEN CO_2 EMISSIONS, INCOME AND OBESITY IN AZERBAIJAN

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Abstract. This study explores the long-run impact of economic growth and environmental quality on obesity in Azerbaijan, a post-Soviet economy undergoing rapid transformation. Recognizing the multidimensional nature of obesity, the analysis integrates macroeconomic (per capita GDP) and environmental (CO_2 emissions) indicators to examine their joint influence on public health. Using annual data from 1991 to 2016, the study employs nonlinear unit root tests (KSS, Sollis, Kruse) to determine integration orders and applies the Augmented ARDL (A-ARDL) approach to account for potential structural breaks. Long-run coefficients are estimated using CCR and FMOLS methods, with diagnostic and stability tests validating model assumptions. Findings confirm a long-run cointegration relationship among the variables. GDP per capita positively affects obesity, while its squared term is negative, indicating an inverted U-shaped pattern. Carbon emissions exert a significant negative impact on obesity. All diagnostic tests affirm the reliability, normality and stability of the estimated model. The results highlight the need for integrated health and environmental policies. Economic development alone may exacerbate obesity unless accompanied by preventive health strategies. Environmental improvements may also coincide with sedentary lifestyles. These insights offer valuable guidance for policymakers in emerging economies facing dual challenges of growth and health transition.

Keywords: *Obesity, GDP per capita, A-ARDL.*

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1. Introduction

Obesity is a condition caused by the accumulation of more fat in the body than normal. Obesity is most common in people with a body mass index (BMI) of 30 or more. This condition is caused by a combination of overnutrition, consumption of high-calorie and unhealthy foods, sedentary lifestyle and genetic factors. Obesity can have serious negative effects on health and increases the risk of many diseases. These include cardiovascular diseases, diabetes, respiratory problems, restricted mobility, cancer risk and psychological effects (Hruby & Hu, 2015). Obesity increases the risk of high blood pressure, high cholesterol and cardiovascular disease (Lavie *et al.*, 2009). It can cause problems in the circulatory system. Obesity is an important risk factor especially in the development of type 2 diabetes. Increased adipose tissue can increase insulin resistance. This problem can narrow the airways and lead to problems such as sleep apnea and shortness of breath. As weight increases, extra load is placed on the joints, especially the knees, leading to diseases such as arthritis. Obesity increases the risk of certain types of cancer, such as stomach, breast, colon and kidney cancers. Obesity is sometimes associated with low self-esteem, depression and other psychological problems.

Obesity is common worldwide, but is more prevalent in some countries. The US is one of the countries with the highest obesity rates. The obesity rate in the US has risen to 40 percent. This is due to a combination of lifestyle, eating habits (fast food and sugary drinks), sedentary lifestyle and genetic factors. Mexico also has a high obesity rate. The prevalence of high-calorie, processed foods and low physical activity contribute to this. Obesity rates are also high in the United Kingdom and Australia. Dietary choices and lifestyle are also important factors here. Obesity rates are also increasing in Arab countries such as Saudi Arabia and the UAE. Obesity is more common here due to over nutrition and sedentary lifestyles. Obesity rates are also increasing in Brazil, Colombia and other Latin American countries. In these regions, changing dietary habits and increased consumption of sweets and fast food are exacerbating the problem.

To prevent obesity, healthy eating habits (avoiding foods high in calories and fat and eating a diet consisting mostly of fruits, vegetables, whole grains and proteins), physical activity (regular exercise to prevent sedentary lifestyles, at least 150 minutes of moderate physical activity per week is recommended), education and awareness (informing people about the health risks of obesity and promoting healthy lifestyles) and appropriately implemented public policies (governments can organize educational programs to combat obesity, increase taxes on sugary drinks and limit advertising of fast food products). Obesity is a major health challenge facing modern society and more action is needed to address it, both at the individual and societal level.

Obesity has a negative impact not only on human health but also on the economic situation of the country. The Obesity Kuznets curve analyzes the relationship between countries' economic development and obesity rates. The Obesity Kuznets Curve is an application of the Kuznets curve developed by Simon Kuznets and attempts to explain the relationship between obesity and economic development. The Kuznets curve generally shows that income inequality increases in the early stages of economic development and decreases as development progresses. The Kuznets Curve for Obesity works in a similar way and explains the relationship between obesity and development. This implies that the relationship changes at a certain stage. Especially in the early stages of economic development, people with more financial means consume more food, leading to an unequal distribution of calories and higher rates of obesity. At lower stages of economic development, people have access to more food, but this leads to excess calories and higher rates of obesity. As economic development progresses and people's incomes rise, health issues are gaining more attention. People are now paying more attention to healthier eating and physical activity. This is leading to a decline in obesity rates. At this stage, people are changing their eating habits, switching to healthier foods and trying to fight obesity by changing their lifestyles.

The Kuznets curve for obesity is used in many fields. This curve is used to analyze obesity rates in developed and developing countries. It helps to understand the relationship between the level of economic development of countries and obesity. This helps public policy makers to make the right decisions about health. The Obesity Kuznets Curve is also used by health researchers and professionals to understand how obesity rates change over time and what economic factors drive these changes. Governments and international organizations can use this theory when planning obesity control programs. Different strategies can be applied at different stages of economic development. The curve is also used in social and economic research because obesity is not only a physical health problem, but is also associated with economic inequality and social development.

The Kuznets Curve of Obesity is a theory that shows that obesity rates increase in the early stages of economic development and as development continues, people pay more attention to health issues and as a result obesity rates decrease. This curve helps to understand the interaction between economic development and people's health and dietary habits and can be a useful tool in shaping health policies.

2. Literature Review

Obesity has become a global problem and there is extensive evidence that obesity prevalence rates have increased over time in many countries. A strong association between obesity and economic development is reported in the literature, but the tendency for obesity growth rates to converge over time has not been investigated. The prevalence of obesity has increased worldwide in recent decades (Finucane *et al*., 2011). Between 1980 and 2008, there was an increase of 0.4 kg per m^2/year for men and 0.4 kg per m^2/year for women in 199 countries. In 2008, approximately 1.47 billion adults worldwide were overweight (BMI $\geq$ 25 kg/m^2), including 205 million men and 297 million women who were obese (BMI $\geq$ 30 kg/m^2). A positive but non-linear relationship has been found between economic development and body weight (Egger *et al*., 2012; Goryakin *et al*., 2014; Gomula *et al*., 2015). However, these studies did not provide a theoretical basis to explain the relationship between weight gain and economic development. Factors associated with weight gain include urbanization (Goryakin & Suhrcke, 2014) economic transition from socialism to capitalism (Gomula *et al*., 2015), trade liberalization (Malik *et al*., 2013) and technological progress (Goryakin & Suhrcke, 2014; Swinburn *et al*., 2011). Only one study (Li *et al*., 2015) has examined the convergence of weight gain across US states. However, this study applied a traditional model of economic development and found that BMI increased faster in poorer countries and also showed that BMI growth rates across countries declined over time. The major drawback of this method is that it does not provide a separate weight gain path for each state.

Applying the dynamic economic development model proposed by Phillips and Sul (2007) and panel data analysis, we examine whether BMI growth rates converge over time across OECD countries. Furthermore, the factors associated with weight gain at the country level are examined through an ecological analysis, providing insights for the implementation of public health policies.

Most theoretical explanations for the relationship between income and obesity have so far focused on the role of food consumption (calorie intake). Some studies suggest that the increase in obesity is explained by the increase in historical periods (Dragone, 2009; Dragone & Ziebarth, 2017; Burke & Heiland, 2007; Levy, 2002, 2009; Dragone & Savorelli, 2012; Strulik, 2014; Mathieu-Bolh, 2020, 2021). Other studies explain the inverse relationship between income and obesity in rich countries (Cutler *et al*., 2015; Fuchs, 1982; Grossman, 1972; Cawley & Ruhm, 2012; Mathieu-Bolh, 2021).

A large body of evidence suggests that obesity has a strong historical association with economic development (Pijl, 2012). Body mass index (BMI) has increased rapidly in 200 countries worldwide over the last 30 years (Finucane *et al*., 2011). However, the rate of growth is not linear. A cross-sectional study covering more than 100 countries shows that BMI increases rapidly with increasing per capita income, reaching $12,500 for women and $17,000 for men (Ezzati *et al*., 2005). Although the increase in BMI has slowed down in some later periods, obesity continues to increase in developed countries (Seidell, 2010). We argue that GDP growth rates may converge over time, especially in countries with similar levels of economic development. The convergence of BMI growth rates has important policy implications, as lessons from developed countries can help prevent or reduce unhealthy weight gain during the economic development process in developing countries.

There is a limited number of similar studies examining the impact of income on health in developed and developing countries and the relationship between health, lifestyle, health expenditures and economic growth using the Simon Kuznets curve and other methods. Although many studies show that age and gender have a significant and positive relationship with income and health, there is also conflicting evidence in this area. For example, research (Jolliffe, 2011) suggests that there is a negative trend in body mass index (BMI) as excess adipose tissue exceeds a threshold and that improvements are associated with healthier BMI values and healthier choices in the US. The study used the unconditional quantile regression (UQR) estimator for analysis and found that obesity rates have never been significantly higher in low-income countries over the past 35 years, with the National Health and Nutrition Examination Survey (NHANES) (Goryakin & Suhrcke, 2014) also showed a non-linear relationship between levels of economic growth and obesity rates among women in more than 56 countries between 1991 and 2009. Similarly, (Grecu & Rotthoff, 2015) conducted an Obesity Kuznets Curve analysis among white women and found support for a positive relationship between a country's per capita income and obesity rates; this relationship was also shown in (Philipson & Posner, 2008; Popkin *et al*., 2012). At the same time, since obesity rates may decrease in low-income countries during periods of economic crisis, these countries may be less likely to experience weight-related health problems. However, (Pongou *et al*., 2006) used cross-sectional data collected in Cameroon in the 1990s to analyze the impact of the economy on health. The results revealed that malnutrition in children increased during the economic crisis in the country, resulting in more overweight children than underweight children; this suggests that obesity will decrease in developing countries during the crisis period. Similarly, (Ruhm, 2016) examined the relationship between economic crises and health and reported that obesity rates decreased significantly during periods of increased unemployment in the US.

There are many experimental studies showing a negative relationship between happiness and obesity. For example, a study by Stutzer (2007) based on cross-sectional data from the 2002 Swiss Health Survey found that obesity reduced the subjective well-being of individuals reporting limited self-control. Katsaiti (2012), using panel data from Germany, the United Kingdom and Australia, finds that obesity has a negative impact on individual happiness in all three countries. Forste and Moore (2012) found a negative association between BMI and happiness using cross-sectional data from the United States. Ul-Hak et al. (2013). A logistic regression study based on data from the United Kingdom showed that obesity had negative effects on happiness; it also showed that obese women were less likely to be unhealthy but more likely to feel unhappy compared to obese men. Latif (2014) examined the impact of obesity on happiness using longitudinal data from Canada covering the years 1994-2006. The results show that obesity significantly reduces happiness in women, but not in men. Kuroki (2016) examined the relationship between obesity and life satisfaction and found that life satisfaction was lower in obese and overweight people. More recently, Habibov and Afandi (2018) conducted a study on 27 different samples from former communist transition countries and found that an increase in BMI decreases happiness.

Research in psychology shows that peers influence adolescents (Chung *et al*., 2017) and adults (Ingledew *et al*., 1998) sports behaviors. Therefore, it is reasonable to assume that sport preferences, like healthy eating preferences, are influenced by peer behavior. The hypothesis of increased peer influence is supported by the growing number of social media users and the increasing number of followers of sports and fitness influencers. For example, the number of Instagram users grew from 100 million in 2010 to 800 million in 2017. In 2017, the top 20 fitness influencers on Instagram had a combined following of nearly 100 million (Influencer Marketing Hub, 2021).

In Africa, approximately 27% of individuals aged 20 years and older are overweight and 8% are obese (Ajayi *et al*., 2016). As many African countries struggle with infectious diseases and poverty-related problems (such as infant mortality, cholera, malnutrition and malaria), the prevalence of chronic diseases is increasing (Asfaw, 2006; Kengne & Awah, 2009). While obesity and overweight used to be considered a problem specific to high-income countries, it is now common in low- and middle-income countries as well. Marshall (2004) noted that developing countries face a "double burden of disease". In some countries in East Africa, for example, malaria and other infectious diseases affect people at an early age. Later in life, a diet rich in high-fat and processed foods puts them at risk of cardiovascular disease and diabetes (Bygbjerg, 2012).

As income increases in low-income countries, the preference for previously unaffordable goods and services such as carbohydrates, red meat, processed foods, alcoholic beverages and cigarettes increases (Burkitt, 1973). Per capita consumption of kilocalories per day per person increases due to excess income; people are eating more, but not always better (Dragone & Ziebarth, 2017). Healthy foods (e.g. foods that are trans fat-free, low in saturated fat and rich in healthy fats) are often more expensive and inaccessible to low-income people (Fogel, 2004; Danaei *et al*., 2013; Banerjee, 2013; Chow *et al*., 2013; Ortega *et al*., 2013). Low-income countries and income groups also have less access to good health services, which may affect preventive measures to reduce the risk of cardiovascular disease.

3. Methodology

In this study, per capita income (GDPPC) and carbon emissions (CO_2) were examined as determining factors on obesity rates, using data from Azerbaijan for the period 1991-2022. Among the variables included in the analysis, GDPPC is considered a macroeconomic indicator representing the level of economic well-being, while carbon emissions are modeled as an environmental factor representing environmental degradation. To understand the time series properties of the series, non-linear stationarity tests were preferred. In this context, the KSS test developed by Kapetanios Shin and Snell- hereafter be referred to as KSS (2003), the STAR-based test proposed by Sollis (2009) that considers asymmetric structures and the Kruse (2011) test were applied. A common feature of these three tests is that they offer a more flexible stationarity analysis by considering dynamics such as structural breaks, asymmetry or regime dependence, especially in situations where traditional linear tests may be insufficient.

The KSS test offers an alternative to the traditional Augmented Dickey Fuller (ADF) (Dickey, 1981) test by being based on a nonlinear STAR (Smooth Transition Autoregressive) process and is suitable for detecting weak nonlinear structures in series (Kapetanios *et al*., 2003). However, this test is not sensitive to asymmetric transitions as it assumes symmetric structures. Therefore, the analysis was further deepened and the

Sollis (2009) test was used to examine whether the series contained asymmetric structures. The Sollis test is a nonlinear unit root test that can evaluate upward and downward transitions differently and focuses particularly on measuring transition asymmetry. The Kruse (2011) test, on the other hand, stands out for its sensitivity to regime changes in time series where structural breaks are effective and can test non-linear structures more accurately.

On the other hand, traditional linear unit root tests such as ADF (Dickey, 1981), PP (1989) or KPSS (1992) tests were not used in this study because these tests do not sufficiently take into account potential structural breaks, nonlinear transitions and regime dependencies in the series. In a country like Azerbaijan, which is undergoing a transition process and has experienced significant economic structural transformations over time, the results of tests based on linear assumptions may be misleading.

Following the stationarity analysis, the Augmented-ARDL (AARDL) test developed by Sam et al. (2019) was preferred to identify possible long-term relationships between the series. The main reason for choosing this method is that it can test non-linear cointegration relationships as an alternative to the linear structure of the classical ARDL approach and can consider lag lengths differently for both dependent and independent variables. The AARDL method provides more robust results, especially for small samples and can test the existence of cointegration relationships more flexibly. Additionally, the model's ability to work with variables at both the I(0) and I(1) levels makes this method suitable for the current data structure.

Traditional cointegration tests such as Engle and Granger (1987) or Johansen (1988) were not preferred in this study because they require all variables to be integrated at the same level. Especially when considering non-linear structures, the assumptions of classical methods are not suitable for the nature of this study.

4. Data and Emprical Findings

Following a detailed explanation of the methodological framework and econometric methods used, this section introduces the data set used in the study and presents the empirical findings obtained.

Table 1. Defination of variables

Symbol	Variables	Unit	Period	Source
OBS	Obesity	Index	1991-2016	World Health Organization
CO_2	Carbon Emissions	Kiloton (kt)		Our World in Data (2024)
GDPPC	Gross Domestic Product Per Capita	Year		World Bank (2024)

It's important to note that the variables used in the study are defined systematically in Table 1. The dependent variable, obesity (OBS), is based on index data provided by the World Health Organization (WHO). This variable reflects the prevalence of obesity at the societal level through indicators such as body mass index. The relevant data were compiled on an annual basis for the period 1991-2022.

The first independent variable, carbon emissions (CO_2), was included in the model to represent environmental degradation. This variable is measured in kilotons (kt) and was obtained from the Our World in Data (2024) dataset. Carbon emissions represent the total amount of carbon dioxide produced from sources such as industrial production, fossil fuel use and transportation. Therefore, it allows for the investigation of the potential effects of environmental pressure on public health.

Another independent variable, gross domestic product per capita (GDPPC), is used as an indicator of macroeconomic welfare. The data is provided by the World Bank (2024) and shows the annual per capita income level. This variable indirectly represents the effects of individuals' economic opportunities on health behaviors and lifestyle.

Overall, the dataset used in the study was created using a holistic approach that encompasses both economic and environmental factors; the data source, measurement unit and period information for each variable are clearly stated. This demonstrates that the analyses are based on a strong foundation in terms of transparency and reproducibility.

Describing the statistical properties of the variables used in the model facilitates a better understanding of the data structure prior to analysis. In this context, Table 2 contains descriptive statistics for the variables obesity index (OBS), carbon emissions (CO_2) and per capita income (GDPC). The mean, median, standard deviation, skewness, kurtosis and Jarque-Bera test results provide important clues about the distribution characteristics of these variables.

Table 2. Descriptive statistics of variables

	OBS	CO_2	GDPC
Mean	13.55	4.024	3076.6
Median	13.01	3.618	2369.5
Maximum	19.90	7.349	5505.9
Minimum	9.103	2.982	1102.5
Std. Dev.	3.193	1.101	1753.4
Skewness	0.443	1.937	0.2883
Kurtosis	2.085	5.586	1.3350
Jarque-Bera	1.755	23.51	3.3635
Probability	0.416	0.000	0.1860
Observations	26	26	26

It shows that the distribution is generally symmetrical because the difference between the mean and the median is quite small. The standard deviation of 3.193 indicates moderate variability. The skewness value of 0.443 is positive, implying that the distribution is slightly right-skewed. The kurtosis of 2.085 indicates a structure close to a normal distribution, while the Jarque-Bera test result (1.755) and the corresponding probability value (0.416) show that the OBS variable does not deviate significantly from a normal distribution.

The mean of the carbon emissions variable is 4.024 and the median is 3.618. Since the mean is significantly larger than the median, the distribution can be said to be right-skewed, which is confirmed by the skewness coefficient of 1.937. The kurtosis value of 5.586 indicates a distribution structure with sharper peaks (leptokurtic) compared to a normal distribution. The Jarque-Bera statistic is quite high (23.51) and significant ($p < 0.01$), which proves that the CO_2 variable deviates from the normal distribution.

For the GDPPC variable, the mean is 3076.6 and the median is 2369.5. Since the mean is significantly higher than the median, there is a right-skewed distribution, supported by the skewness value of 0.2883. The kurtosis value of 1.3350 indicates a more flat (platykurtic) structure than a normal distribution. The Jarque-Bera statistic is 3.365, with a significance level of 0.186. This indicates that the GDPPC variable does not deviate statistically significantly from a normal distribution.

The direction and strength of linear relationships between variables in the dataset were examined through correlation analysis. Figure 1, created for this purpose, shows a correlation heat map that visually presents the Pearson correlation coefficients between the three main variables. Color intensity indicates the strength of the relationship, while *** and * stars indicate significance levels of 1% and 10%, respectively.

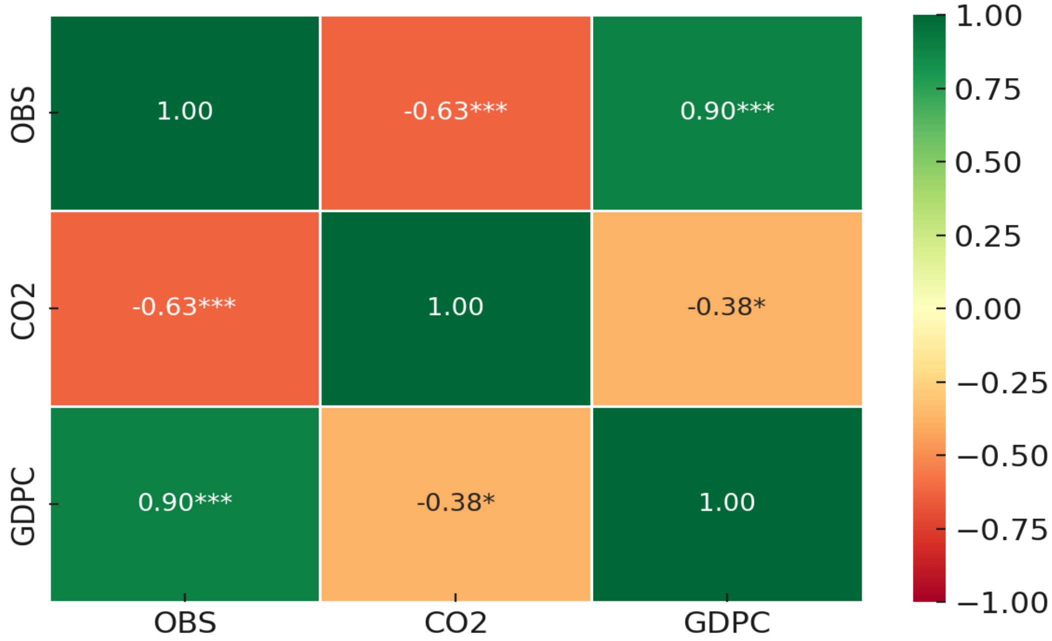


Figure 1. Correlation Heatmap of variables

A strong and negative correlation of -0.63 is observed between obesity and carbon emissions. This correlation is statistically significant at the 1% significance level ($p < 0.01$). This finding suggests that an increase in carbon emissions may have an effect in reducing obesity rates. Alternatively, it could be argued that periods with lower carbon emission levels may represent unhealthy lifestyles, which could be associated with an increase in obesity. However, whether this relationship is causal should be tested using time series analysis.

We found a very strong and positive relationship between obesity and per capita income, with a correlation coefficient of 0.90. This relationship is also statistically significant at the 1% level ($p < 0.01$). This suggests that increases in income levels may contribute to higher obesity rates. In the literature, this situation is often interpreted as the "prosperity trap" or a "side effect of modern lifestyles": factors such as individuals leading more sedentary lives, easier access to high-calorie foods and the spread of unhealthy consumption habits as income increases can increase the risk of obesity.

There is a moderately negative relationship between these two variables at a level of -0.38 and this relationship is statistically significant at the 10% significance level ($p < 0.10$). This result indicates a trend toward a decrease in carbon emissions as per capita income increases. This situation can be explained by improvements in energy efficiency, the transition to environmentally friendly technologies or the effectiveness of sustainable development policies as income levels rise. However, this relationship is weak and should be interpreted with caution.

Although descriptive statistics and correlation analysis provide important information about the general relationship structure between variables, a common limitation of these methods is that they neglect the time dimension. In other words, fixed summary values such as mean, variance or correlation coefficient cannot reveal the dynamic behavior and structural changes of variables over time. For this reason, time series graphs are presented in Figure 2. Through these graphs, the trends, breaks and simultaneous movement patterns of the variables of obesity, carbon emissions and per capita income over time have been visually analyzed.

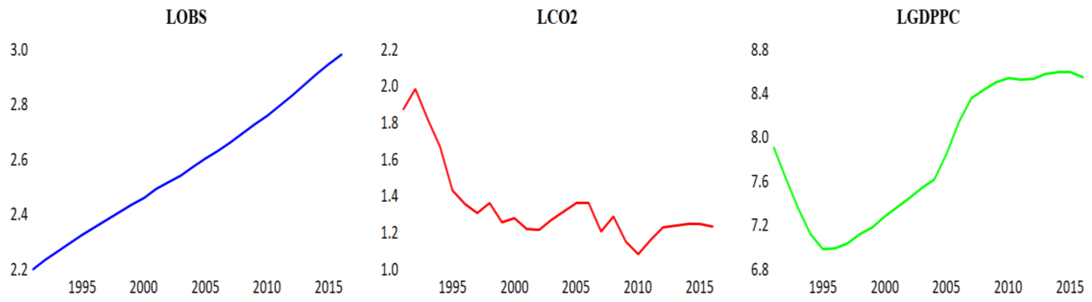


Figure 2. Time-series graphics of variables

The graph for the LOBS variable shows a steady, monotonic and continuously increasing trend throughout the period 1991-2015. There is no sign of any pause or break in this increase. The graph clearly shows that obesity has been structurally increasing over time. This situation may be the result of both lifestyle changes associated with increased prosperity and increased physical inactivity and dietary habits in society as a whole. At the same time, this continuous increase also suggests that the dependent variable may not be stationary.

The LCO_2 graph begins with a sharp downward trend after 1991. There was a particularly rapid decline between 1991 and 1995. After 1995, the graph took on a wavy and horizontal structure. This situation suggests that carbon emissions are sensitive to external shocks such as economic crises and changes in energy policy. Furthermore, the fact that the CO_2 data has a trendless, horizontally fluctuating structure indicates that it should be carefully tested for stationarity.

The LGDPPC graph shows a decline between 1991 and 1995, followed by a noticeable recovery and upward trend after 1996. In particular, a rapid growth trend is observed after 2000 and this upward trend continues until 2008. Although there was a brief pause due to the 2008 global crisis, the overall trend indicates a positive growth trend. This structure shows that the strong positive correlation between economic growth and obesity has become more pronounced over time. Additionally, since the per capita income data also exhibits a trend-containing structure, it should be subjected to appropriate unit root tests prior to stationarity procedures.

Even though the general trends in time series graphs give us important visual clues about how variables behave over the long term, just looking at the graphs isn't enough to figure out for sure if the series is stationary. As clearly seen in the graphs, while a distinct trend structure is observed in the obesity and per capita income series, the carbon emissions series exhibits a fluctuating but non-systematic structure. However, the visual profiles of the series are notable not only for containing trends but also for exhibiting non-linear transition structures and asymmetric behavior patterns. These observations necessitate questioning not only whether the variables are stationary at the level but also whether this stationarity is achieved through a linear or non-linear process. For this reason, in the following section, the stationarity structure of the series is analyzed using non-linear unit root tests such as KSS (2003), Sollis (2009) and Kruse (2011) tests, rather than traditional linear tests.

Table 3. Unit Root Results

Variables	*KSS (2003)*		*Sollis (2009)*		*Kruse (2011)*		
	Constant						
	Test stat	*Lag*	*Test stat*	*Lag*	*Test stat*	*Lag*	*Results*
LOBS	-2.59	1	3.61	1	6.21	1	I(1)
LCO2	-4.06***	0	5.97**	0	12.9**	0	I(0)
LGDPPC	-2.09	0	1.92	0	7.81	0	I(1)
	Constant & Trend						
LOBS	-2.18	1	3.92	1	10.8	1	I(1)
LCO2	-3.79**	0	5.81*	0	14.7**	0	I(0)
LGDPPC	-2.86	0	4.38	0	9.61	0	I(1)

***, **, * indicates that the null hypothesis is rejected at 1%, 5% and 10% significance level, respectively

According to the KSS (2003) test results, the carbon emissions (LCO_2) variable was found to be significant at the 1% level with a test statistic of -4.06 and was assessed as stationary (I(0)). In contrast, the test statistics for the obesity (LOBS) and per capita income (LGDPPC) variables were not significant, leading to the conclusion that these two series are not stationary at the level, i.e., they are stationary at the first difference (I(1)). This finding supports the notion that the LOBS and LGDPPC variables exhibit a trend structure.

Similar results were obtained according to the Sollis (2009) test. The carbon emissions variable was found to be significant at the 5% level with values of 5.97 and 5.81 in the constant and constant-trend models, respectively and was classified as I(0). The test statistics for the other two variables, LOBS and LGDPPC, remained below the critical values, indicating that these variables are not stationary despite exhibiting non-linear asymmetric processes and that they contain a unit root.

The Kruse (2011) test is a test that stands out for its sensitivity to structural breaks. In this test as well, only the LCO_2 variable was found to be significant at the 5% level, confirming its stationarity. The test statistics obtained for the LOBS and LGDPPC variables are not significant, indicating that these variables contain a unit root and exhibit I(1) properties. Thus, all three tests consistently indicate a non-stationary structure for LOBS and LGDPPC and a stationary structure for LCO_2.

In conclusion, the findings indicate that the series have different degrees of integration. While the carbon emission variable is stationary at the level (I(0)), the obesity and per capita income variables have a stationary structure at the first difference (I(1)). This structure provides a suitable framework for applying models such as the classical ARDL model and the nonlinear Augmented-ARDL model, enabling the establishment of long-term relationships between the series.

$$LOBS = f(LCO_2, LGDPPC, LGDPPC^2) \tag{1}$$

In this study, the econometric relationship among the variables included in the analysis was formally specified through the Equation (1) presented earlier in the paper.

Based on this model specification, the A-ARDL (Augmented Autoregressive Distributed Lag) approach developed by Sam et al. (2019) was employed for estimation. While the traditional ARDL method is suitable for analyzing long-term relationships between variables with different integration orders (I(0) and I(1)), the clear upward trend observed in the dependent variable - obesity - and the potential presence of structural breaks necessitated a more flexible approach. Therefore, Equation (1) was estimated using the A-ARDL technique (Equation (2)), which allows for endogenous structural changes in the dependent variable, leading to more robust and consistent long-run parameter estimates. The detailed estimation results are presented in Table 4.

$$\Delta LOBS_{t} = \alpha_0 + \beta_0 LOBS_{t-1} + \beta_1 LCO2_{t-1} + \beta_2 LGDPPC_{t-1} + \beta_3 LGDPPC^{2}{}_{t-1} + \sum_{i=0}^{p-1} c_{0,i}\Delta LOBS_{t-i} +$$
$$\sum_{j=1}^{q_{j-1}} c_j \Delta LCO2_{t-i} + \sum_{j=1}^{q_{j-1}} c_j \Delta LGDPPC_{t-i} + \sum_{j=1}^{q_{j-1}} c_j \Delta LGDPPC^{2}_{t-j} + \sum_{j=1}^{q_{j-1}} c + d_1 \Delta LCO2_t +$$
$$d_2 \Delta LGDPPC_t + d_3 \Delta LGDPPC^{2}_{t} + \varepsilon_i \, (2)$$

Table 4. A-ARDL cointegration results

Model	**ARDL order**	**Break Time**	**$F_{OVERALL}$**		**$F_{INDEPENDENT}$**	**Results**
Case IV	**2,0,4**	**2001**	**12.072*****		**7.2162*****	**Cointegration**
Critical Values	**Peseran et al. (2001)**		**Narayan (2005)**		**Sam et al. (2019)**	
	Lower	**Upper**	**Lower**	**Upper**	**Lower**	**Upper**
1%	3.79	5.38	4.10	5.81	3.20	6.09
5%	2.92	4.16	3.21	4.29	2.61	4.67
10%	2.53	3.29	2.54	3.67	2.37	3.83

***, **, * indicates that the null hypothesis is rejected at 1%, 5% and 10% significance level, respectively

Table 4 presents the results of the Augmented-ARDL (A-ARDL) cointegration analysis, which takes into account possible structural breaks in the dependent variable. The ARDL order of the model has been set as (2,0,4), which indicates two lags for the obesity variable, zero lags for carbon emissions (CO_2) and four lags for per capita income (GDPC). Additionally, within the A-ARDL framework, the year 2001, identified as a significant breakpoint in the series' history, was considered the period during which structural changes were integrated into the model. This break coincides with the years when Azerbaijan's economy began to experience rising oil revenues and entered a process of structural transformation.

The $F_{overall}$ statistic (12.072), which tests the overall significance of the model, exceeds the upper limit values of 1% proposed by both Pesaran et al. (2001) and Narayan (2005). This strongly indicates the existence of a long-term relationship between the variables. Similarly, the $F_{independent}$ value (7.2162), which tests the contribution of the independent variables to the model, is well above the critical threshold (6.09 at the 1% level) proposed by Sam et al. (2019), providing further evidence supporting the model.

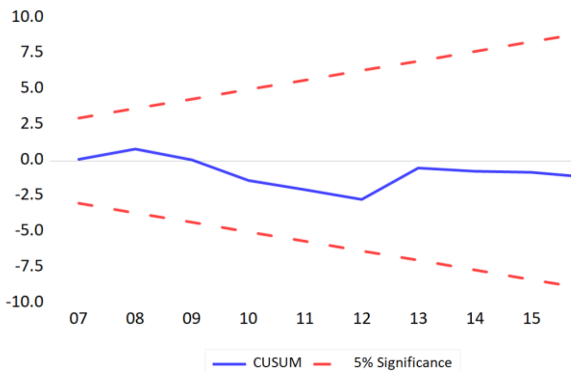
According to the three different reference value sets (Pesaran, Narayan and Sam) used in the analysis, the results obtained confirm each other. All three methods show that there is a long-term cointegration relationship between obesity, carbon emissions and per capita income variables. In particular, the A-ARDL approach developed by Sam et al. (2019) allows for more reliable results by considering structural breaks and dynamic transitions. The findings indicate that environmental and economic factors have a long-term and statistically significant impact on obesity dynamics in Azerbaijan.

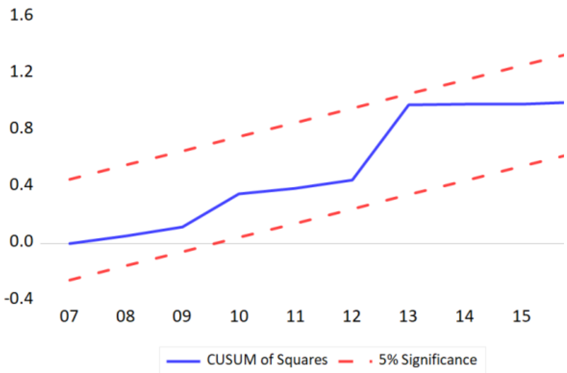
These results are important both for policymakers and public health planning. In the next phase, the direction and coefficients of this long-term relationship will be estimated to analyze how the effects on obesity are shaped in economic terms.

In the previous section, a long-term cointegration relationship between the dependent variable and explanatory variables was identified using the A-ARDL model. However, to assess the reliability of this relationship and the validity of the model results, it is essential to test whether the model's basic assumptions are met. In particular, assumptions such as the normal distribution of regression residuals, lack of autocorrelation, constant variance and stability of parameters over time are factors that directly affect the model's predictive power. Therefore, Table 5 presents the diagnostic test results for the A-ARDL model and the graphical findings of the CUSUM and CUSUM of Squares tests, which measure parameter stability.

Table 5. Diagnostics of A-ARDL

R^2	*F-statistics*	*JB*	*BG-LM*	*White*	*R-R*
0.9999	27681.4	0.3006	1.7161	0.4358	0.9721
Parameters Stability Tests					
CUSUM			CUSUM SQ		





In the previous section, a long-run cointegration relationship was established between the dependent and explanatory variables using the Augmented-ARDL (A-ARDL) model. However, in order to validate the reliability of this relationship and ensure the robustness of the model, it is essential to test whether the fundamental assumptions of the regression framework are satisfied. Specifically, assumptions such as the normality of residuals, absence of autocorrelation, homoscedasticity and stability of parameters over time directly affect the credibility of the estimated coefficients. Therefore, Table 5 presents the diagnostic test results for the A-ARDL model along with graphical evidence from the CUSUM and CUSUM of Squares parameter stability tests.

The explanatory power of the model is remarkably high, with an R^2 value of 0.9999, indicating that 99.99% of the variation in the dependent variable is explained by the model. Such a high R^2 reflects an almost perfect fit to the data. Moreover, the F-statistic (27681.4) is extremely high, strongly confirming the overall significance of the model.

The Jarque-Bera (JB) test, which assesses whether the residuals are normally distributed, yields a p-value of 0.3006, which exceeds the 5% significance level. This indicates that the null hypothesis of normality cannot be rejected and therefore, the residuals follow a normal distribution, which is crucial for the validity of standard statistical inference.

The Breusch-Godfrey LM (BG-LM) test is employed to detect autocorrelation in the residuals. The test statistic of 1.7161 is not statistically significant, indicating that there is no evidence of serial correlation in the residuals. This confirms that the residuals are independent over time, satisfying a key assumption of the ARDL framework.

The White test is used to detect heteroskedasticity. The result of 0.4358 suggests that there is no heteroskedasticity, implying that the variance of the error terms remains constant across observations. This supports the unbiasedness and efficiency of the estimated coefficients.

The Ramsey RESET test evaluates the functional form specification of the model. The RESET statistic (0.9721) is not significant, indicating that the model is not misspecified and that the functional form has been correctly selected.

The bottom section of Table 5 presents the CUSUM and CUSUM of Squares tests, which are used to assess whether the model's parameters remain stable over time. In both graphs, the blue test lines remain within the red dashed boundaries representing the 5% significance limits. This clearly indicates that the parameter estimates are stable throughout the sample period and that no structural break is observed in the model. Stability is particularly critical in A-ARDL models that explicitly account for structural changes, making these findings highly supportive of the model's reliability.

In summary, all diagnostic tests indicate that the key assumptions of the A-ARDL model are satisfied. The results confirm normality, absence of autocorrelation, homoscedasticity, correct functional form and parameter stability, reinforcing the validity and reliability of the long-run relationships estimated in the model.

Table 6. Long-run Estimates

Variables	CCR	FMOLS
Constant	8.5753	7.3908
LCO2	-0.4926***	-0.4869***
LGDPPC	0.5706***	0.5708***
LGDPPC2	-0.0196***	-0.0197***
D2001	-0.0252	-0.0172
R^2	0.8989	0.9000
SER	0.0763	0.0759

Table 6 presents the long-run effects of carbon emissions (LCO_2), gross domestic product per capita (LGDPPC), the square of income ($LGDPPC^2$) and a structural break dummy variable (D2001) on obesity (OBS) as the dependent variable. The estimations were conducted using both Canonical Cointegrating Regression (CCR) and Fully Modified Ordinary Least Squares (FMOLS) methods. The results are highly consistent across both techniques, allowing for coherent interpretation.

Firstly, the carbon emissions (LCO_2) variable has a negative and statistically significant effect on obesity at the 1% level in both CCR (−0.4926) and FMOLS (−0.4869) models. This finding suggests that a reduction in carbon emissions is associated with an increase in obesity; in other words, as environmental pollution decreases, obesity rates tend to rise. This paradoxical relationship may reflect the socio-economic transition in developing countries where urbanization, industrialization and lifestyle changes coexist.

The gross domestic product per capita (LGDPPC) variable is positive and highly significant (at the 1% level) in both models (CCR: 0.5706, FMOLS: 0.5708). This indicates that higher income levels are associated with higher obesity rates. The positive association can be attributed to increased access to unhealthy food, sedentary lifestyles and shifting consumption patterns as income rises.

Conversely, the coefficient for the square of income ($LGDPPC^2$) is negative and also significant at the 1% level (CCR: −0.0196, FMOLS: −0.0197). This confirms a nonlinear (inverted U-shaped) relationship between income and obesity. In the early stages of income growth, obesity tends to rise; however, after reaching a certain income threshold, obesity begins to decline. This outcome is consistent with the "obesity-income quadratic hypothesis" widely discussed in the literature.

The D2001 dummy variable, which accounts for the structural break year, has a negative coefficient in both estimations (CCR: −0.0252, FMOLS: −0.0172), but it is statistically insignificant. This suggests that the structural transformation experienced in Azerbaijan's economy around 2001 did not have a direct and significant impact on obesity levels.

The overall explanatory power of the models is remarkably high. The R^2 is 0.8989 in the CCR model and 0.9000 in the FMOLS model, indicating that approximately 90% of the variation in obesity can be explained by the long-run determinants. Moreover, the standard error of regression (SER) is relatively low in both models (below 0.08), reinforcing the reliability and precision of the estimated coefficients.

The long-run estimations reveal significant insights for public health and environmental policy in Azerbaijan. The positive and statistically strong relationship between per capita income and obesity highlights the growing health risks associated with rising economic prosperity. Policymakers should recognize that economic growth alone does not guarantee improved health outcomes, particularly in the context of lifestyle-related non-communicable diseases. As income rises, there is a critical need for parallel investments in health education, urban planning that promotes physical activity and taxation policies that discourage excessive consumption of unhealthy foods. Additionally, the negative and significant association between carbon emissions and obesity suggests that environmental factors may indirectly shape health behaviors and outcomes. This points to the necessity of an integrated policy framework where environmental sustainability and public health objectives are aligned. Coordinated efforts in both domains could yield synergistic benefits by promoting both cleaner environments and healthier populations.

The findings of this study align with and extend previous empirical literature on the income-obesity relationship. The observed inverted U-shaped pattern between income and obesity corroborates the "obesity Kuznets curve" hypothesis, which posits that obesity increases at early stages of economic development but decreases after surpassing a certain income threshold (Popkin, 2012; Egger, 2012, Swinburn, 2011). Similar results have been documented in middle-income economies undergoing rapid structural and dietary transitions. Furthermore, the negative long-run association between carbon emissions and obesity presents a less explored dimension in the literature, suggesting that environmental externalities may inversely mirror lifestyle shifts. While some prior studies have focused on the health costs of pollution, few have considered how improvements in environmental quality may correlate with sedentary behavior and processed food dependence. Thus, this study contributes to the expanding discourse by offering a dual-perspective model that links both economic and environmental determinants to obesity in a transitional economy context.

5. Conclusion

This study investigated the long-run determinants of obesity in Azerbaijan by focusing on the roles of carbon emissions and economic development, using annual data from 1991 to 2022. Employing nonlinear unit root tests and the Augmented ARDL (A-ARDL) approach, the analysis accounted for structural breaks and potential nonlinear dynamics within the time series. The findings revealed a robust long-run cointegration relationship among the variables, validating the suitability of the A-ARDL framework for modeling health-related outcomes in the presence of complex macroeconomic and environmental interactions.

The results from both CCR and FMOLS estimations confirmed that per capita income has a statistically significant positive effect on obesity, whereas its squared term exhibits a negative influence, suggesting an inverted U-shaped relationship. This pattern supports the hypothesis that obesity initially rises with income growth but eventually declines as higher income levels facilitate access to healthier lifestyles and awareness. Additionally, carbon emissions were found to have a significant negative effect on obesity, implying that reductions in environmental pollution may coincide with lifestyle transitions that inadvertently promote sedentary behavior and unhealthy consumption patterns.

Diagnostic tests affirmed the statistical validity and stability of the estimated models, while CUSUM and CUSUM of Squares tests verified parameter constancy throughout the sample period. These outcomes not only strengthen the empirical reliability of the study but also highlight the complex and multidimensional nature of obesity in a transitioning economy.

From a policy perspective, the results underscore the necessity of adopting integrated strategies that simultaneously address environmental quality and public health. As Azerbaijan continues to develop economically, proactive public health policies - particularly those targeting dietary behavior, physical activity and environmental awareness - will be essential to mitigating the long-term societal costs of obesity. The study contributes to the literature by providing evidence on the dual role of economic and ecological variables in shaping public health trends and offers valuable insights for decision-makers in emerging economies.

6. Policy Recommendations

The empirical findings of this study offer valuable implications for policymakers aiming to address the growing public health challenge of obesity in Azerbaijan. The established long-run relationship between obesity, per capita income and carbon emissions highlights the necessity for multi-sectoral and integrated policy responses that extend beyond the healthcare domain alone.

1. Promote Health-Conscious Urbanization: Given the positive link between income and obesity, urban planning efforts must prioritize the development of environments that facilitate active lifestyles. Investments in pedestrian infrastructure, public parks and accessible recreational facilities can counterbalance sedentary behaviors that often accompany economic modernization.

2. Implement Fiscal Instruments for Nutritional Behavior: The government should consider introducing targeted fiscal policies such as subsidies for fruits and vegetables and taxes on sugar-sweetened beverages or ultra-processed foods. These measures can reshape consumer behavior in favor of healthier dietary choices, particularly in low- and middle-income households where price sensitivity is high.

3. Integrate Public Health Campaigns with Environmental Policy: The negative association between carbon emissions and obesity suggests that lifestyle shifts accompanying environmental improvements may inadvertently increase health risks. Therefore, environmental and health ministries should coordinate campaigns that promote sustainable living alongside physical well-being, emphasizing active transport, organic food consumption and reduced screen time.

4. Target Socioeconomic Inequalities in Health: The nonlinear income-obesity relationship implies that beyond a certain threshold, higher income may lead to better health outcomes. Thus, interventions must be tailored to vulnerable income groups who are at higher risk of obesity due to limited access to health education, nutritious food and preventive services. Social safety nets and community-based nutrition programs can play a critical role in narrowing this gap.

5. Monitor and Address Lifestyle Transitions: As Azerbaijan undergoes socioeconomic transformation, government agencies should monitor evolving consumption and physical activity trends. Establishing a national obesity surveillance system and conducting regular household health and nutrition surveys can help identify emerging risks and evaluate policy effectiveness in real time.

6. Institutionalize Cross-Sector Collaboration: To ensure sustainability and efficacy, obesity prevention must be institutionalized through cross-sector collaboration. Ministries of health, education, environment, agriculture and finance should work together under a national strategy to tackle obesity from both demand and supply-side perspectives.

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