The European Journal of Health Economics (2021) 22:1095–1101
https://doi.org/10.1007/s10198-021-01308-x

ORIGINAL PAPER

Obesity Kuznets curve and the reality of eco-income ellipsoids (EIE)

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Received: 18 September 2020 / Accepted: 15 April 2021 / Published online: 28 April 2021

Abstract
Health is regarded as a universal asset and how this translates into sustainable development has remained a subject of discourse in the growth and health literature. This disposition is in line with the United Nations Sustainable Development Goals-3, 8, and 13, which highlight the need for good health, sustainable economic growth, and environmental sustainability, respectively, especially for the United States. To this end, this study explores the nexus of turning point such that a subsequent growth in income level decreases the prevalence of obesity. Similarly, the study examined the existence of the minimum turning point after which the increase in the ecological footprint (EFP) escalates the prevalence of obesity. A recent time-series data of annual frequency from 1975 to 2016 are used for econometrics analysis to examine the reality of ellipsoidal hypothesis. The autoregressive distributed lag techniques are adopted for this study. Thus, an empirical investigation revealed that higher income per capita level leads to obesity until a certain threshold. Thus, the inverted U-shaped relationship between income and obesity is validated, while the nexus between EFP and obesity resonates with the U-shaped. The validity of these two forms of (obesity-income-EFP) relationship is captured as the ellipsoidal hypothesis. Additionally, an increase in life expectancy decreases obesity prevalence in the United States. Based on these outcomes, policy mechanisms should be geared toward adopting more sustainable productivity approaches and more push for higher income status for the citizenry.

Keywords Health status · Sustainable growth · Environmental sustainability · Obesity Kuznets curve · The United States

JEL Classification C32 · D1 · I1

Introduction

Following the foremost study of Kuznets [9] that hinted at the imbalance between countries advancement and the increasing economic inequality, Grossman and Krueger [4] and the report of the World Bank [20] further observed the environmental side of every economic progression. In recent times, health perspectives, which include weight gain/loss, dietary, behavioral health patterns are increasing unmasking an income effect relationship. For instance, an economic intuition would suggest a rise in unhealthy behavioral practices such as overfeeding when income continues to increase, especially if health is to be a normal good. In such case, a return to healthy behavioral practices, such as accessing healthy dietary, and having good rest ensue afterward, thus reducing the risk of overweight and obesity vis-à-vis obesity Kuznets curve (OKC) [3, 7, 17]. In the phase of incessant global economic uncertainties, it is expected to bemoan the increasing link in the global trend of obesity and socio-economic inequalities. Thus, the global trends in obesity are now increasingly linked with the dynamics of income growth, a trend of rural-to-urban movement, trade openness, globalization, risk factors, and other related factors [5, 10, 11], 21]. Importantly, racial/ethnic disparity, cultural, and dietary factors are increasingly becoming topical in the obesity discourse [22].

In the United States, for instance, the prevalence of obesity reportedly increased from 30.5 to 42.4% in 1999–2000 through 2017–2018 [1]. With this disturbing trend, and the surge in the level of food consumption among Americans (according to the [16]), a more hazardous dimension is the ecological footprint (EFP) deficit profile of the United States since 2015 [2]. The nexus between obesity

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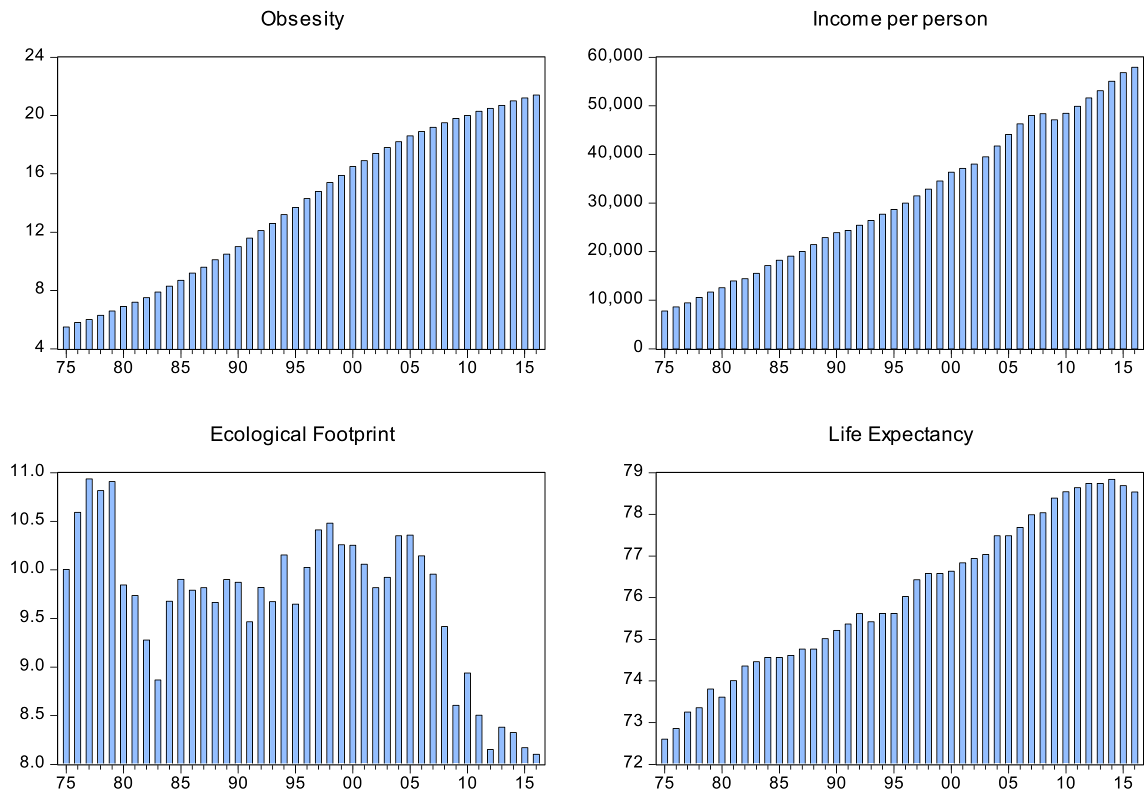

Fig. 1 A representation of the trends of obesity, income per head, ecological footprint, and life expectancy in the United States

and ecology (environment) has recently gained attention in both the United States and other developing countries [18]. The relevance of environment and obesity has gained recent attention especially from the perspective of environmental chemicals in the atmosphere which was documented in the study of Hill and Peters [6] that further outlined that chemical atmosphere induce food quality and by extension BMI especially in childhood [13]. The connection between obesity and the environment is resonated in the study of Wilding [19]. In specific, Global Footprint Network [2] noted that American households consume 5.44 global hectares (gha) per person footprint. Thus, leaving a significant deficit (1.6 gha per capita) of an EFP as a necessity that is always augmented through government interventions. In addition to this seemingly 'new normal' backdrop, the annual median household income (MHI) in the United States has observably increased since 2013, given the vast increase experienced in 10 of the country's 25 largest metropolitan areas [15]. For instance, the United States Census [15] reported that the real MHI topped $61,937 (an increase of 0.8%) from 2017 to 2018. Thus, with the United States' income-obesity trend that is graphically illustrated in Fig. 1, querying the validity of OKC is not out of place.

In this context, the current study is focused on examining the nexus of obesity-ecological footprint-income in the United States vis-à-vis the validity of obesity Kuznets curve. In a novel approach, and in the framework of OKC, the directional pathway of the EFP and income trajectory is observed. Thus, the current study proceeds to scrutinize for the first time in the literature the probable joint occurrence of the inverted U-shaped (from an obesity-income relationship) and the U-shaped (from obesity-ecological footprint relationship), otherwise illustrated as the ellipsoidal hypothesis. Considering the aforementioned perspective of the trilemma of obesity, income, and EFP, the effect of life expectancy is considered simultaneously by employing an empirical methodology with the autoregressive distributed lag (ARDL). In all, the contextual framework of the study is expected to be a significant contribution to the existing body of knowledge of obesity Kuznets curve.

A unique dimension is adopted in this study such that the presentations from other sections are conveyed in an outlined pattern. As such, the employed methodology, discussion of the implied results and a concluding remark are all presented in "Materials and methods", "Empirical results and interpretation" and "Conclusion and policy implications", respectively.

Materials and methods

Data and source

This study augments the conventional Obesity Kuznets curve by the incorporation of the EFP as measures of environmental indicator in conjunction with life expectancy in the US for the first time. The choice of the variables is informed by the crusade of the United Nations Sustainable development Goals (UN-SDGs). This study confirms with SDGs 3, 8, and 13. That is good health which is needed for sustainable development, sustainable economic growth, and mitigation of environmental issues respective that resonates goals 3,8 and 13. Where GDPC is gross domestic product per capita measured as (constant \$2010) to measure income level, EFP as a measure for environment sourced from Global Footprint Network. While LEX denotes life expectancy measure for health longevity. The variables are: obesity (percentage of defined population with a body mass index (BMI) of 30 kg/m^2 or higher) that is sourced from global health observatory data repository (https://apps.who.int/gho/data/view.main), EFP is Ecological Footprint (Global Network), economic growth (GDP) and LEX (Life expectancy) retrieved from World Bank Development Indicator database. The data span for the current study ranges from 1975 to 2016.

Empirical test process

The empirical sequence of this study follows three paths. First, basic pre-test of preliminary visual investigation of underlined variables and summary statistics. Second, the test of stationarity status of the variable by the use of the conventional unit root test of augmented Dickey–Fuller (ADF). Third, the investigation of long-run equilibrium relationship and magnitude of the relationship among the variables under review with the help of ARDL bounds testing methodology and the short and long-run regression.

Model specification

To investigate the relationship between income level and income square and obesity for the case of the US. The following functional form is expressed in line with the empirical backing in the extant studies [3, 17]

$$\text{Obs} = f(\text{GDPC}, \text{GD}^2, \text{EFP}, \text{EFP}^2, \text{LEX}), \tag{1}$$

$$\begin{aligned}\text{LnObs}_t =&\alpha + \beta_1\text{GDPC}_t + \beta_2\text{GDPC}_t^2 \\ &+ \beta_3\text{EFP}_t + \beta_4\text{EFP}_t^2 + \beta_5\text{LEX}_t + \varepsilon_t.\end{aligned} \tag{2}$$

Here, α and $\beta's$ represent intercept term and slope elasticities parameters of the fitted model to be estimated.

ε_t is the stochastic term at time t (where t = 1975, 1976, 1977, …, 2016). The double-logarithm transformation has been carried out on all variables, this is to aid interpretation of the variables in elasticity form.

Furthermore, on the reliance on economic intuition is that we expected $\beta_1 > 0$ while $\beta_2 < 0$ if that the case the obesity Kuznets curve is validated while for β_3 and β_4 could be positive or negative which could either validate the U-shaped or inverted U-Shaped nexus between the dependent variable and environmental sustainability. Finally, $\beta_5 < 0$ indicating the role of longevity on quality of health. However, the need to conduct more analysis is crucial to either validate or refute the apriori expectations. Furthermore, with the maximum order of integration of the variables as $I(1)$, i.e. stationary after first difference. The Pesaran et al. [12] ARDL method is applied as next step to explore simultaneously the short- and long-run dynamics of the highlighted variables in Sect. 2 over a sampled period:

$$\begin{aligned}\text{lnOBESITY}_t =&\beta_0 + \sum_{k=1}^{p}\beta_a\text{lnOBESITY}_{t-k} + \sum_{k=0}^{q}\beta_{b,k}\text{lnGDPC}_{t-k} \\ &+ \sum_{k=0}^{q}\beta_{c,k}\text{lnGDPC}_{t-k}^2 + \sum_{k=0}^{r}\beta_{d,k}\text{lnEFP}_{t-k} \\ &+ \sum_{k=0}^{s}\beta_{e,k}\text{lnEFP}_{t-k}^2 + \sum_{k=0}^{t}\beta_{f,k}\text{lnLEX}_{t-k} + \varepsilon_t.\end{aligned} \tag{3}$$

Subsequently, this study provides simultaneously the short-run and long-run equations with an accompanying adjustment parameter via the error correction model. The error correction term (ECT) shows the pace of adjustment in case of disequilibrium. Thus, the long-run coefficients are presented as:

$$\begin{aligned}\text{lnOBESITY}_t =&\Psi_0 + \rho_1\text{lnOBESITY}_{t-1} + \rho_2\text{lnGDPC}_{t-1} \\ &+ \rho_3\text{GDPC}_{t-1}^2 + \rho_4\text{lnEFP}_{t-1} + \rho_5\text{lnEFP}_{t-1}^2 \\ &+ \rho_6\text{lnLEX}_{t-1} + \sum_{k=1}^{p}\pi_k\text{lnOBESITY}_{t-k} \\ &+ \sum_{i=0}^{q}\theta_{1,i}\Delta\text{lnGDPC}_{t-i} + \sum_{i=0}^{q}\theta_{2,i}\Delta\text{lnGDPC}_{t-i}^2 \\ &+ \sum_{j=0}^{q}\theta_{3,k}\Delta\text{lnEFP}_{t-j} + \sum_{k=0}^{u}\theta_{4,k}\Delta\text{lnEFP}_{t-k}^2 \\ &+ \sum_{i=0}^{q}\theta_{5,i}\Delta\text{lnLEX}_{t-i} + \varepsilon_t,\end{aligned} \tag{4}$$

where Δ is a differenced operator, the long-run coefficients are obtained from $\sigma_i = \hat{\rho}_i/(1-\hat{\rho}_1)$, $i = 1,2,3,4,5$. Furthermore, the ECT is derived from $\text{ect}_{t-1} = \text{lnOBESITY}_t - \text{lnGDPC}_t - \text{lnGDPC}_t^2 - \text{lnEFP}_t - \text{lnEFP}_t^2 - \text{lnLEX}_t$. The

Table 1 Basic summary Statistics of variables under consideration

(a)	OBS	GDPC	EFP	LEX
Mean	13.7762	31,143.48	9.6910	76.0560
Median	14.0000	29,329.29	9.8322	75.8244
Maximum	21.4000	57,927.52	10.9368	78.8415
Minimum	5.50000	7801.457	8.1043	72.6049
Std. dev.	5.3241	15,220.42	0.7614	1.8638
Skewness	− 0.0845	0.1533	− 0.6634	− 0.0319
Kurtosis	1.5545	1.7692	2.6843	1.8363
Jarque–Bera	3.7063	2.8152	3.2559	2.3771
Probability	0.1567	0.2447	0.1964	0.3046
Observations	42	42	42	42

(b)

Unit root	ADF-Fisher level	First difference (Δ)
ln GDPC	− 2.6648	− 4.154*
ln EFP	− 1.819	− 6.577*
ln LEX	− 2.248	− 6.716*
ln OBS	− 0.760	− 3.647*

*Represents the statistical significance at 1% (i.e. probability value < 001). Also, Δ indicate the first difference for the unit root. The fitted model incorporates both intercept and trend as the best performance model for the variables under review in terms of stationarity properties test

Here GDPC is gross domestic product per capita (constant 2010 USD), EFP as measure for environment sourced from Global Footprint Network. While LEX denotes life expectancy measure for health longevity

coefficients $\rho_1, \rho_2, \rho_3, \rho_4, \rho_5$ and ρ_6 are the long-run impacts of OBESITY, GDPC, square of GDPC, EFP, square of EFP and LEX on obesity the dependent variable.

Empirical results and interpretation

This section presents the empirical estimation and interpretation. The first point of call is the preliminary test of basic statistics and visual graphical plot to give a glimpse of how the data fare. Table 1 presents the basic summary statistics that report measures of central tendencies like mean, median, mode, and range and measure of dispersion like the mean deviation and standard deviation as well as also symmetry status of the data alike skewness, peakness reported by Kurtosis among others. Table 1 shows real income per capita with the highest average over the sampled period (31,143$) followed by life expectancy while obesity. In terms of deviation from their averages, the standard deviation reports a significant deviation from their mean. Furthermore, all series show negative skewness except real income that is positively skewed. In general, all series statistically pass the normality test as shown by the Jarque–Bera probability, thus suggesting all underlined variables are normally distributed.

Subsequently, this study proceeds to investigate the stationarity status of the variables. This is pertinent to avoid the error of spurious regression. The current study reports the conventional unit root test of ADF, Table 1 renders the results of a unit root. The result shows that all the variables are integrated of order 1 ~ I(1) as all variables were non-stationary at the level form but after first difference, they all were stationary as we reject the null hypothesis of unit root at probability value < 001. The next step is to explore the long-run (equilibrium) relationship between the variables. The aid of the Pesaran Bounds test affirms the equilibrium relationship as the *F*-statistics is statistically greater than the upper bounds at ($P < 0.01$) statistical rejection level, thus suggesting that there exists a long-run bound between obesity, real income level, life expectancy, and EFPs over the sampled period.

Furthermore, to establish the magnitude of the relationship between the outlined variables, the ARDL regression is fitted with obesity as the dependent variable and other explanatory variables (life expectancy, real income, and EFPs). The estimated model is robust as the ECT is negative and statistically significant with a magnitude of over 5% per annual with the contribution of the explanatory variables. The regression shows that income and real income square shows the inverted U-shaped relationship with obesity for the US. Real income shows a positive statistical ($P < 0.01$)

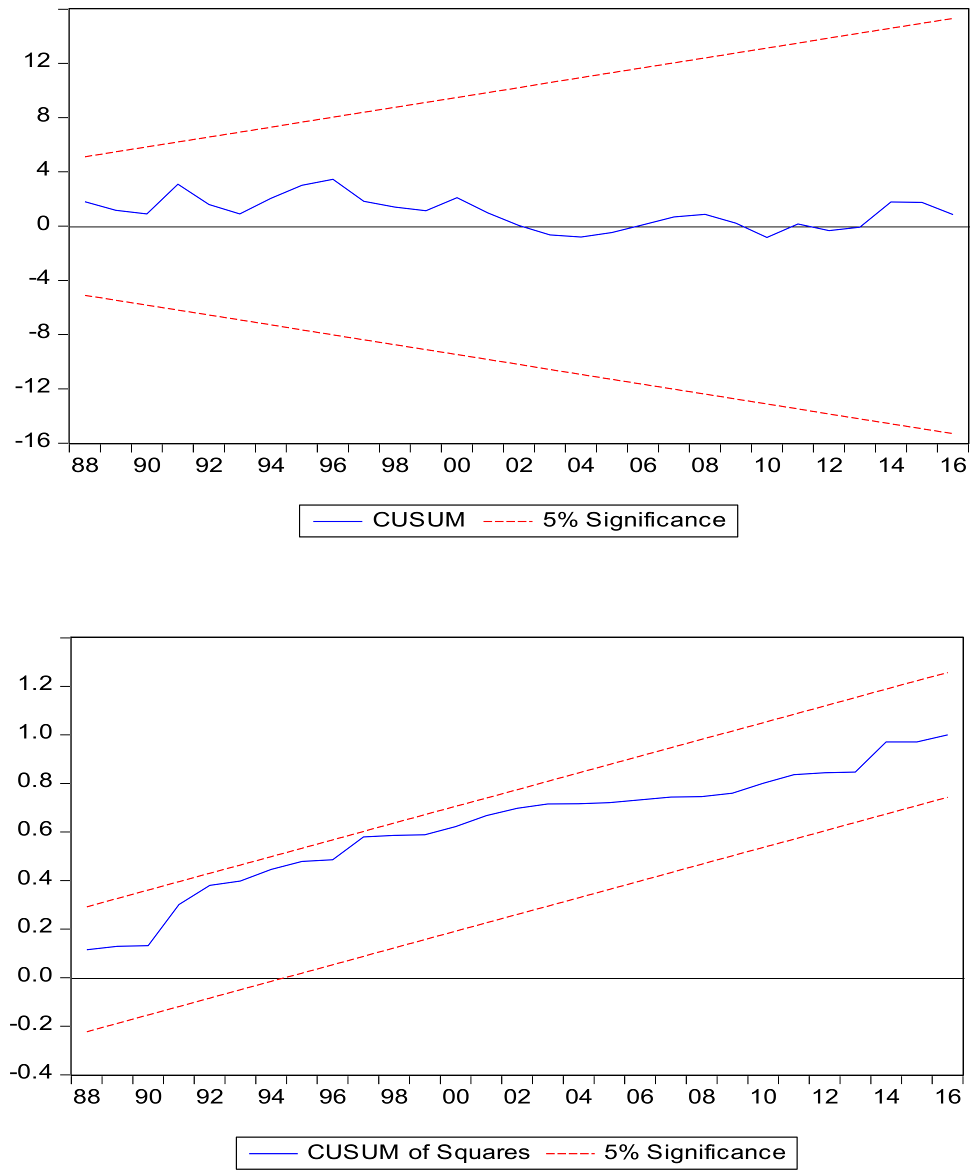

Fig. 2 Graphical plot of model stability as reported by the cumulative sum and the square of cumulative sum

level with obesity. Empirical results show that a 1% increase in real income per capita increases obesity by 0.8029% while real income square decreases obesity by 0.0413 in the short run, while in the long run, same inverted U-shaped relationship is established between real income level and obesity level in the US. This finding is in line with the study of Kim and von dem Knesebeck [8]. This suggests that income level at a higher threshold increase in obesity in the US, although, until a certain threshold known as the turning point obesity decrease. For the case of the US according to our study, the turning point for income level is estimated at 10,3914$ in the long run.[1] The current study is consistent with the study of (see Grecu and Rotthof [3] and Windarti [17]) that validates the obesity Kuznets curve hypothesis (OKC).

In addition, the study revealed a significant relationship between EFP proxy for environmental indictor and obesity. The result found that a 1% increase in EFP decreases obesity by 2.5104% while the square of EFP increases obesity by 0.5654% in the short run, thus validating the U-Shaped nexus between EFP and obesity. That is, an increase in EFP decreases obesity until a minimum threshold of EFP is attained. However, as EFP continues to increase, the prevalence of obesity becomes severe, thus dampens the quality of life. The plausible logic for this is seen in the US low EFP deficit, even as the country began to experience a deficit EFP since July 2015. In the same fashion, the OKC

[1] The turning point is computed by $\frac{\beta_1}{(2\beta_2)}$.

Table 2 The relationship estimates obesity, income, and ecological footprint (long and short run)

Variable	Coefficient	Std. error	*T*-stat	*P* value
Δ LGDPC	0.8029*	0.1254	6.4029	0.0000
Δ LGDPC(− 1)	− 0.0753***	0.0405	− 1.8553	0.0737
Δ LGDPC2	− 0.0413*	0.0062	− 6.6537	0.0000
Δ LEFP	− 2.5104*	0.6078	− 4.1298	0.0003
Δ LEFP2	0.5654*	0.1365	4.1411	0.0003
Δ LEX	− 0.7959*	0.2876	− 2.7668	0.0097
ECT(− 1)	− 0.0548**	0.0245	− 2.2341	0.0333
Long run coefficients				
LGDPC	15.6328*	7.3041	2.1403	0.0409
LGDPC2	− 0.7522***	0.3683	− 2.0425	0.0503
LEFP	− 45.8027**	20.2736	− 2.2592	0.0316
LEFP2	10.3152**	4.5106	2.2868	0.0297
LEX	− 6.2335	6.4644	− 0.9642	0.3429
Constant	0.2863	28.3406	0.0101	0.9920

ARDL bounds testing to long-run

Test statistic	Value	*k*
F-statistic	13.0798***	5

Critical value bounds

Significance	*I*(0) Bound	*I*(1) Bound
10%	2.26	3.35
5%	2.62	3.79
2.5%	2.96	4.18
1%	3.41	4.68

Model diagnostic tests
Normality: 3.4395 (0.1791)
Serial correlation: 1.0784 (0.3543)
Heteroscedasticity: 0.7629 (0.6619)
Ramsey: stable

Superscripts indicates *,**,*** 0.01, 0.05 and 0.10 percent represents statistical rejection level, respectively, and difference operator (Δ) represents first difference, () denotes *P* values

Akaike information criterion (AIC) is chosen over other lag selection criteria given our study sample frame and the AIC performed and presented the most robust estimates in the regression

hypothesis (U-shaped relationship between income and obesity) is established in the long run for the case of the US over the sampled period. Thus, this study observed the reality of ellipsoidal hypothesis (a combination of U- and inverted U-shaped relationship) in the interaction of obesity, EFP vis-à-vis environmental quality, and income.

Life expectancy shows an inverse relationship between longevity of life and obesity for the US. That is, an increase in life expectancy decreases obesity. This suggests that a higher quality of life in terms of longevity improves health with less obesity status. The fitted model is adequate and suitable for policy directions as Fig. 2 shows the stability of the fitted model as reported by The CSUM and CUSU square stability test. The fitted model is also free from serial correlation issues and Heteroscedasticity given failure to reject their respective null hypothesis (Table 2).

Conclusion and policy implications

Although the concept of obesity Kuznets curve has been studied, argued, and generally conceived to be realistic for many countries across the globe, the conceptual framework presented in the current study is billed to be significant to the OKC literature. For a few fascinating reasons, this has presented a novel perspective. First, the OKC (an inverted

U-shaped) hypothesis is validated for the United States, i.e. there is valid statistical evidence of a rise and fall relationship between income and obesity in the United States. Second, the findings put forward here, for the first time, affirmed a significant 'fall and rise' relationship between obesity and EFP, i.e. a U-shaped hypothesis. Thus, this study presents that there is an ellipsoidal hypothesis relationship (a combination of the U-shaped and the inverted U-shaped) arising from the trends of obesity, income, and EFP in the United States. Lastly, this study noted a significant and negative relationship between obesity and life expectancy of Americans, especially in the short term. Considering the intrinsic nature of the relationship among the aforementioned factors, the study offered useful policy orientation to the state governments in the United States and other interest or stakeholding institutions.

As a policy, healthy living through sustainable productivity should not be compromised in an attempt to compensate for the already deficit EFP in the United States. As such, a more sustainable development approach should be engaged in compensating for the 1.6 gha per person of EFP in the United States. Specifically, a more sustainable approach to production of goods and services should be further adopted. By implication, priority is further placed on the production of more healthy food-related items to mitigate obesity and other health-related challenges. In addition, through extensive economic development, a higher income growth could be achieved; such they will further trigger a decline in the prevalence of obesity in the United States. Thus, caution should be placed on higher income levels, as higher income is associated with l increase in macroeconomic indicators and social issues like obesity and environmental elements.

Moreover, because this study is the first to consider the existence of the ellipsoidal hypothesis in the context of OKC, and for the United States, conducting similar studies for cases across the globe will be an expected empirical necessity.

References

1. Centres for Disease Control and Prevention:https://www.cdc.gov/obesity/data/adult.html (2020). Accessed 5 July 2020
2. Global Footprint Network: https://www.footprintnetwork.org/ (2019). Accessed 5 July 2020
3. Grecu, A.M., Rotthoff, K.W.: Economic growth and obesity: findings of an obesity Kuznets curve. Appl. Econ. Lett. **22**(7), 539–543 (2015)
4. Grossman, G., Krueger, A.: Economic growth and the environment. Q. J. Econ. **110**, 353–377 (1995). https://doi.org/10.2307/2118443
5. Hillier-Brown, F.C., Bambra, C.L., Cairns, J.M., Kasim, A., Moore, H.J., Summerbell, C.D.: A systematic review of the effectiveness of individual, community and societal level interventions at reducing socioeconomic inequalities in obesity amongst children. BMC Public Health **14**(1), 834 (2014)
6. Hill, J.O., Peters, J.C.: Environmental contributions to the obesity epidemic. Science **280**(5368), 1371–1374 (1998)
7. Koplan, J.P., Dietz, W.H.: Caloric imbalance and public health policy. J. Am. Med. Assoc. **282**, 1579–1581 (1999). https://doi.org/10.1001/jama.282.16.1579
8. Kim, T.J., von dem Knesebeck, O.: Income and obesity: what is the direction of the relationship? A systematic review and meta-analysis. BMJ Open **8**(1), e019862 (2018)
9. Kuznets, S.: Economic growth and income inequality. Am. Econ. Rev. **45**, 1–28 (1955)
10. Malik, V.S., Willett, W.C., Hu, F.B.: Global obesity: trends, risk factors and policy implications. Nat. Rev. Endocrinol. **9**(1), 13–27 (2013)
11. Miqueleiz, E., Lostao, L., Ortega, P., Santos, J.M., Astasio, P., Regidor, E.: Trends in the prevalence of childhood overweight and obesity according to socioeconomic status: Spain, 1987–2007. Eur. J. Clin. Nutr. **68**(2), 209–214 (2014)
12. Pesaran, M.H., Shin, Y., Smith, R.J.: Bounds testing approaches to the analysis of level relationships. J. Appl. Econ. **16**(3),289–326 (2001)
13. Poston, W.S.C., II., Foreyt, J.P.: Obesity is an environmental issue. Atherosclerosis **146**(2), 201–209 (1999)
14. Twarog, J.P., Politis, M.D., Woods, E.L., Daniel, L.M., Sonneville, K.R.: Is obesity becoming the new normal? Age, gender and racial/ethnic differences in parental misperception of obesity as being 'About the Right Weight.' Int. J. Obes. **40**(7), 1051–1055 (2016)
15. United States Census: U.S. median household income up in 2018 from 2017. https://www.census.gov/library/stories/2019/09/us-median-household-income-up-in-2018-from2017.html#:~:text=Real%20median%20household%20income%20in,1.8%25%20and%203.3%25%20annually (2019). Accessed 5 July 2019
16. United States Department of Agriculture: Obesity. https://nifa.usda.gov/topic/obesity (2019). Accessed 5 July 2020
17. Windarti, N., Hlaing, S.W., Kakinaka, M.: Obesity Kuznets curve: international evidence. Public Health **169**, 26–35 (2019)
18. WHO: Obesity and overweight, factsheet no. 311 [website]. Geneva, Switzerland: World Health Organization (updated Mar 2011). http://www.who.int/mediacentre/factsheets/fs311/en/ (2011). Accessed 29 Dec 2020
19. Wilding, J.: Are the causes of obesity primarily environmental? Yes. BMJ (2012). https://doi.org/10.1136/bmj.e5843
20. World Bank: World Development Report 1992. Oxford University Press, New York (1992)
21. Wu, S., Ding, Y., Wu, F., Li, R., Hu, Y., Hou, J., Mao, P.: Socio-economic position as an intervention against overweight and obesity in children: a systematic review and meta-analysis. Sci. Rep. **5**, 11354 (2015)
22. Zilanawala, A., Davis-Kean, P., Nazroo, J., Sacker, A., Simonton, S., Kelly, Y.: Race/ethnic disparities in early childhood BMI, obesity and overweight in the United Kingdom and United States. Int. J. Obes. **39**(3), 520–529 (2015)

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