Original Research

Obesity Kuznets curve: international evidence

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ABSTRACT

Objectives: The obesity epidemic has prevailed worldwide and is currently recognized as a global pandemic disease. Given the argument that various socio-economic features contribute to substantial differences in obesity rates across countries, economic development can also be considered a crucial factor of such variation. This study examines the relationship between economic development and each of three weight-related health statuses (rates of overweight, obesity, and morbid obesity).
Study design: This study uses panel data analysis.
Methods: Using country-level panel data of 130 countries during the period from 1975 to 2010, we apply dynamic panel data analysis to mitigate possible endogeneity problems.
Results: The main results show a clear pattern of the obesity Kuznets curve, i.e. a non-linear relationship between a country's income per capita and its weight-related health status, for both males and females. For low-income countries, as incomes increase, the weight-related health status deteriorates; thus, an increase in incomes raises the health risk. In contrast, for high-income countries, as incomes increase, the weight-related health status improves; thus, an increase in incomes reduces the health risk.
Conclusions: The policy implications from our analysis include the argument that a strong initiative for health policy targeting obesity prevention is required for middle-income countries, many of which are currently experiencing high economic growth.

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Introduction

The epidemic of obesity has prevailed worldwide, including advanced and developing countries, and it is currently regarded as a global pandemic disease. Obesity increases the risk of adverse health conditions because it is associated with

chronic medical conditions, reduced health-related quality of life, increased health care and medication spending,[1] and decreased life expectancy;[2,3] thus, the burden is not only on the individual's healthcare cost but also on the indirect cost incurred by society through the reduction in productivity and income tax.[4–6] Overweight and obese individuals have

stereotypes as unproductive, undisciplined, and unmotivated,[7] and they can affect the self-confidence, and even the wages, of young adults.[8] A decrease in body mass index (BMI) in overweight and obese men and women improves health outcomes and cost savings.[9] The causal link between obesity and environmental emissions highlights the importance of addressing the obesity epidemic on public health and environmental grounds.[10]

According to non-communicable disease (NCD) Risk Factor Collaboration (NCD-RisC), the prevalence of obesity increased from 3.2% to 10.8% among men and from 6.4% to 14.9% among women during the period from 1975 to 2014. Substantial differences in obesity rates exist across countries. The updated report by the Organization for Economic Co-operation and Development (OECD) in 2017 shows that the top two countries with the highest obesity rates are the United States (38.2%) and Mexico (32.4%), whereas the countries with the lowest rates are Japan (3.7%) and South Korea (5.3%). Many factors contribute to the variation in obesity across countries, including lifestyle, cultural, and socio-economic factors,[11] genetic influences, globalization,[12−15] and economic freedom.[16,17] Among them, technological change and economic factors can also be considered crucial determinants of the obesity epidemic.[18−20]

Similar to the concept of the Kuznets curve of a non-linear relationship between income inequality and development,[21] health inequality and development also have a non-linear relationship called the health Kuznets curve.[22−24] The argument of the non-linear relationship has recently extended to personal health, proxied by obesity.[25] Under the obesity Kuznets curve, as incomes rise, weight gain occurs since individuals can afford excess food; thus, caloric imbalance leads to an increase in obesity rates.[26] Economic development with technological advancement creates inexpensive and delicious foods, pushing lives with more sedentary lifestyles and less physical activity and thus causing the obesity epidemic.[20,27,28] However, given the argument that health is a normal good, continued increases in incomes enable people to shift consumption to healthier foods and to invest more in their overall personal health, which eventually reduces obesity rates. The case of the United States shows a negative income gradient in BMI at the obesity threshold and that increases in income are correlated with healthier BMI values at the tails of the BMI distribution.[29] The state- and country-level panel data also present the non-linear relationship between income levels and obesity rates.[25,30] A spline regression analysis over 175 countries reveals that income is positively related to BMI up to US$ 3000, with a less significant relationship beyond that level.[31]

Our study also extends the income-obesity analysis across countries with an emphasis on obesity Kuznets curve contexts. We use country-level 5-year interval panel data of 130 countries during the period from 1975 to 2010. Differently from previous studies, we apply dynamic panel data analysis to estimate empirical models with obesity rates as a dependent variable and income levels as an independent variable, allowing for a partial adjustment or persistence of obesity rates and unobserved panel-level fixed effects. One methodological issue is that the models may suffer from endogeneity problems, including dynamic effects related to persistence of obesity rates, as a result of which the ordinary least squares (OLS) method derives biased estimators. To mitigate such problems, this study applies system generalized method of moments (GMM) estimators, which include additional moment conditions under the assumptions that there is no autocorrelation in the idiosyncratic errors and that the panel-level effects are uncorrelated with the first difference of the first observation of the dependent variable.[32,33]

The main results show a clear pattern of the obesity Kuznets curve, i.e. a non-linear relationship between health status and income level for both males and females. In addition, the critical value of the income level differentiating the sign of the relationship is larger for males than for females, implying that as incomes increase, females tend to pay more attention to health as a normal good. The policy implications from our analysis suggest that a strong initiative for health policy targeting obesity prevention is required for middle-income countries, many of which are currently experiencing high economic growth. The rest of this article is organized as follows: Section Methods explains the methodology and data, and Section Results presents the estimated results, with important implications related to the obesity Kuznets curve. The Discussion section concludes.

Methods

The primary objective of this study is to evaluate the obesity Kuznets curve by estimating the inverted U-shaped relationship between obesity rates and economic development, which can be captured by real gross domestic product (GDP) per capita over 130 countries. The obesity Kuznets curve requires that the prevalence of the obesity epidemic rises in the early stage of development but eventually declines after the income level reaches some critical level. To address this issue, we estimate the following dynamic panel data model:

$$Y_{i,t} = \beta_0 Y_{i,t-1} + \beta_1 LGDPPC_{i,t} + \beta_2 LGDPPC_{i,t}^2 + \gamma Z_{i,t} + \mu_i + \tau_t + \varepsilon_{i,t},$$

where $Y_{i,t}$ is the weight-related health status in country i at time t, $LGDPPC_{i,t}$ is the log of the income level of country i, $Z_{i,t}$ is a vector of other control variables that are expected to relate to the weight-related health status, μ_i is the country fixed effects, τ_t is the time-specific effects, and $\varepsilon_{i,t}$ is the error term. The model includes the squared term of $LGDPPC_{i,t}$ to capture the concavity or the non-linear relationship, and it also includes the lag of the weight-related health status because health status has a time persistent property.

This study considers three country-level measures of weight-related health status: age standardized rates of overweight, obesity, and morbid obesity for adults (OVR, OBE, and MOBE, respectively), which are taken from the Global Health Observatory data repository from the World Health Organization. People are classified as overweight, obese, and morbidly obese if their BMI is more than 25, 30, and 40, respectively. Income level is measured by the log of real GDP per capita (LRGDPPC), which is obtained from the Penn World Table. The inclusion of the country fixed-effects controls for time-invariant characteristics, such as climatic conditions and unmeasured cultural factors, and the inclusion of time-

specific effects absorbs any time-varying differences common to all countries.

In choosing our set of control variables, we follow standard practices as much as possible. The model includes trade openness (TRADE), which is measured by the sum of exports and imports divided by GDP. Trade with interaction among countries promotes health through the transfer of knowledge, technology, and medical supplies.[34] In contrast, TRADE promotes a globalized lifestyle with the increased exposure to and consumption of imported goods, which can be recognized as a main driver of obesity.[15] In addition, we include the ratio of the urban population (URBAN) to capture urbanization since the previous studies suggest that people in urban areas generally have more access to food and participate in fewer physical activities[35] and that urbanization has been driving the rise in overweight and obesity.[30]

As robustness checks, the models include two additional control variables, female labor participation (FLP) and the Gini index (GINI). Female working hours have an impact on healthy eating and the physical activity of females and their family members[36–38] because females are often responsible for maintaining the health and weight of their family members. The GINI, which is a common measure of within-country income inequality, is also included because income inequality plays a role in explaining obesity and overweight.[13,39] Increases in income have a sizable positive impact on public health, but the strength of the relationship is influenced by changing levels of poverty and inequality.[40] Although this argument suggests that our model specification may not be enough, the inclusion of GINI in the model would be helpful to check the empirical validity of our baseline results. The data on trade flows and urbanization are taken from the Penn World Table and the United Nations Population Division, respectively. The data on FLP and the GINI are obtained from the World Development Indicators. Table 1 shows the list of sample countries in this study. Table 2 presents the descriptions of the variables used in this study. Tables 3 and 4 show the summary statistics and correlation matrix. Our

Table 1 — List of sample countries.

East Asia & Pacific	Europe & Central Asia	Latin America & Caribbean	Middle East & North Africa	South Asia	Sub-Saharan Africa	North America
Australia	Albania	Antigua and Barbuda	United Arab Emirates	Bangladesh	Angola	Canada
Brunei Darussalam	Austria	Argentina	Djibouti	India	Benin	United States
Cambodia	Bulgaria	Bahamas	Algeria	Sri Lanka	Burkina Faso	
China	Cyprus	Barbados	Egypt, Arab Rep.	Maldives	Botswana	
Fiji	Denmark	Belize	Iran, Islamic Rep.	Nepal	Central African Republic	
Indonesia	Finland	Bolivia	Iraq	Pakistan	Côte d'Ivoire	
Japan	France	Brazil	Israel		Cameroon	
Korea, Rep.	Germany	Chile	Jordan		Congo, Rep.	
Lao PDR	Greece	Colombia	Kuwait		Cabo Verde	
Malaysia	Hungary	Costa Rica	Lebanon		Gabon	
Mongolia	Iceland	Dominica	Morocco		Ghana	
Myanmar	Ireland	Dominican Republic	Malta		Guinea	
New Zealand	Italy	Ecuador	Saudi Arabia		Gambia	
Philippines	Netherlands	El Salvador	Tunisia		Guinea-Bissau	
Thailand	Norway	Grenada			Kenya	
Vietnam	Poland	Guatemala			Liberia	
	Portugal	Haiti			Lesotho	
	Romania	Honduras			Madagascar	
	Spain	Jamaica			Mali	
	Sweden	Mexico			Mozambique	
	Switzerland	Nicaragua			Mauritania	
	Turkey	Panama			Mauritius	
	United Kingdom	Paraguay			Malawi	
		Peru			Namibia	
		St. Kitts and Nevis			Niger	
		St. Lucia			Nigeria	
		St. Vincent and the Grenadines			Rwanda	
		Suriname			Senegal	
		Trinidad and Tobago			Sierra Leone	
		Uruguay			São Tomé and Principe	
		Venezuela, RB			Swaziland	
					Chad	
					Togo	
					Tanzania	
					Uganda	
					South Africa	
					Zambia	
					Zimbabwe	

Table 2 – Key variables and data sources.

Variable	Description	Source
Dependent variables		
Obesity rate (OBE)	The percentage of the population of a given country that is obese in log	Global Health Observatory Data (World Health Organization)
Overweight rate (OVR)	The percentage of the population of a given country that is overweight in log	Global Health Observatory Data (World Health Organization)
Morbid obesity rate (MOBE)	The percentage of the population of a given country that is morbid obese in log	Global Health Observatory Data (World Health Organization)
Independent variables		
LGDPPC	Expenditure-side real GDP at chained PPPs (in mil. 2011US$)/Population (in millions) in log	Penn World Table (PWT) 9.0
TRADE	Trade is the sum of exports and imports of merchandise measured as a share of current PPPs	PWT 9.0
URBAN	Urban population refers to people living in urban areas as defined by national statistical offices	United Nations Population Division
FLP	Female labor force as a percentage of the total labor force	World Development Indicators (WDI)
GINI	Gini index measures	World Bank, Development Research Group

FLP, female labor participation; GINI, Gini index; URBAN, urban population; LGDPPC, log of real GDP per capita; TRADE, trade openness.

Table 3 – Summary statistics of key variables.

Variable	No. of obs.	Mean	Std. dev.	Max	Min
OVR (Both)	910	34.624	16.411	70.800	5.600
OVR (Male)	910	31.822	18.829	70.400	4.100
OVR (Female)	910	37.185	15.387	73.400	6.500
OBE (Both)	910	10.516	7.417	34.600	0.200
OBE (Male)	910	7.474	6.688	31.200	0.100
OBE (Female)	910	13.445	8.914	43.200	0.300
MOBE (Both)	896	10.808	7.710	36.408	0.186
MOBE (Male)	910	0.230	0.382	4.362	0.001
MOBE (Female)	910	1.130	1.300	8.328	0.001
LGDPPC	910	8.667	1.216	12.272	4.997
TRADE	910	0.481	0.342	1.839	0.005
URBAN	910	51.266	23.238	98.263	4.721
FLP	630	0.5069	0.166	0.876	0.081
GINI	356	42.762	9.284	65.800	23.000

FLP, female labor participation; GINI, Gini index; URBAN, urban population; LGDPPC, log of real GDP per capita; TRADE, trade openness; OBE, obesity rate; OVR, overweight rate, MOBE, morbid obesity rate.

sample covers 130 countries during the 5-year interval period from 1975 to 2010, and the number of observations is 910. Because variables of FLP and GINI are limited, the number of observations is decreased in the model estimations for the robustness checks.

One crucial limitation is that our model may suffer from endogeneity problems. Dynamic panel data models include some lags of the dependent variable as covariates, as a result of which the model allows for a partial adjustment mechanism, and they also contain unobserved panel-level fixed effects. By construction, the lagged dependent variables are correlated with the unobserved panel-level effects. In addition, explanatory variables are not strictly exogenous; thus, they are correlated with past and possibly current realizations of the error. For example, obesity could influence the income level. Moreover, the model may contain heteroskedasticity and autocorrelation within individual units' errors, but not across them. In such cases, standard estimators become inconsistent. Arellano and Bond develop a consistent GMM estimator for the model.[41] However, the Arellano-Bond estimator performs poorly if the autoregressive parameters or the ratio of the variance of the panel-level effect to the variance of the idiosyncratic error are relatively large. Poor instruments in the difference GMM estimator cause inefficient and biased coefficient estimates.[41,42]

To address this issue, the system GMM, which includes additional moment conditions, is developed.[33] This estimator is designed for panel data with many panels and short periods, under the assumptions that there is no autocorrelation in the idiosyncratic errors and that the panel-level effects are uncorrelated with the first difference of the first observation of the dependent variable. The system GMM estimator combines the use of lagged levels of the series as instruments for the predetermined and endogenous variables in equations in first differences and the use of lagged differences of the dependent variable as instruments for equations in levels. The system GMM estimator derives more

Table 4 – Correlation matrix of key variables (full sample).

Variable	OVR (B)	OVR (M)	OVR (F)	OBE (B)	OBE (M)	OBE (F)	MOBE (B)	MOBE (M)	MOBE (F)	LGDPPC	TRADE	URBAN	FLP
OVR (B)	1.000												
OVR (M)	0.972	1.000											
OVR (F)	0.955	0.858	1.000										
OBE (B)	0.971	0.925	0.950	1.000									
OBE (M)	0.939	0.972	0.820	0.940	1.000								
OBE (F)	0.914	0.809	0.972	0.962	0.811	1.000							
MOBE (B)	0.972	0.928	0.949	1.000	0.942	0.960	1.000						
MOBE (M)	0.640	0.666	0.554	0.727	0.784	0.618	0.728	1.000					
MOBE (F)	0.668	0.573	0.731	0.802	0.660	0.843	0.798	0.776	1.000				
LGDPPC	0.767	0.824	0.631	0.730	0.808	0.603	0.733	0.605	0.490	1.000			
TRADE	0.363	0.394	0.290	0.341	0.395	0.263	0.341	0.299	0.200	0.507	1.000		
URBAN	0.839	0.856	0.752	0.786	0.821	0.693	0.789	0.534	0.478	0.774	0.373	1.000	
FLP	−0.375	−0.307	−0.439	−0.391	−0.260	−0.470	−0.390	−0.081	−0.285	−0.238	−0.003	−0.293	1.000
GINI	−0.083	−0.227	0.101	−0.078	−0.258	0.068	−0.082	−0.215	0.054	−0.270	−0.181	−0.098	0.051

FLP, female labor participation; GINI, Gini index; URBAN, urban population; LGDPPC, log of real GDP per capita; TRADE, trade openness; OBE, obesity rate; OVR, overweight rate, MOBE, morbid obesity rate.
(B), (M), and (F) mean both sex, males, and females, respectively.

efficient results. Thus, this study employs the two-step system GMM estimator to estimate the empirical model. Lacking valid instruments for the income level, we cannot claim to have fully resolved all endogeneity issues. However, the system GMM estimator mitigates some of them since this methodology is suitable for the adjustment process of the dependent variable with independent variables that are not strictly exogenous.

Results

Tables 5–7 present the estimated results of the OLS, the fixed effects models, and the dynamic panel data models with the two-step system GMM estimators in the overweight, obesity, and morbid obesity equations, for all people (both sex), males,

and females, respectively. Table 8 summarizes the results of the two-step system GMM estimators and the peak-out level of real GDP per capita when the results support the obesity Kuznets curve. When applying the system GMM estimators, we need to confirm that there is no second-order serial correlation. As the tests for the specification for the absence of serial correlation, the Arellano-Bond test statistic for second order autocorrelation (AR(2)) show that in every model, the null hypothesis of no second-order serial correlation cannot be rejected, as required by the specification. In addition, the Hansen tests for exogeneity show that the J-statistic has a P-value greater than 0.10 in all models; thus, we cannot reject the null hypothesis that the instruments as a group are exogenous in the system GMM estimation, as required by the specification. The main interest of our study is whether the income-obesity relationship shows the obesity Kuznets curve.

Table 5 – Estimated results – Both sex.

Variable	Overweight ratios			Obesity ratios			Morbid obesity ratios		
	OLS	FE	GMM	OLS	FE	GMM	OLS	FE	GMM
Lag of dependent variable	1.022***	0.814***	1.006***	1.088***	0.996***	1.074***	1.087***	0.995***	1.083***
	(0.003)	(0.020)	(0.009)	(0.004)	(0.015)	(0.010)	(0.004)	(0.015)	(0.009)
LGDPPC	2.913***	1.470**	4.403***	1.343***	0.329	2.184***	1.384***	0.098	1.652***
	(0.368)	(0.571)	(1.017)	(0.176)	(0.330)	(0.542)	(0.190)	(0.298)	(0.412)
LGDPPC^2	−0.171***	−0.082**	−0.261***	−0.078***	−0.018	−0.132***	−0.080***	−0.003	−0.097***
	(0.021)	(0.036)	(0.060)	(0.010)	(0.021)	(0.032)	(0.011)	(0.019)	(0.024)
TRADE	0.256***	0.002	0.361	0.154***	0.125	0.159	0.140***	0.068	0.250
	(0.087)	(0.120)	(0.311)	(0.051)	(0.078)	(0.154)	(0.053)	(0.072)	(0.257)
URBAN	0.003	0.079***	0.018***	0.001	0.029***	0.011***	0.001	0.032***	0.005*
	(0.002)	(0.010)	(0.006)	(0.001)	(0.005)	(0.003)	(0.001)	(0.005)	(0.003)
AR(2)			0.251			0.257			0.292
Hansen test			0.281			0.119			0.246
No. of obs.	910	910	910	910	910	910	896	896	896
No. of countries	130	130	130	130	130	130	130	130	130
R-squared	0.998	0.991		0.997	0.993		0.997	0.993	

LGDPPC, log of real GDP per capita; FLP, female labor participation; GINI, Gini index; URBAN, urban population; TRADE, trade openness; OLS, ordinary least squares; FE, fixed effects; GMM, generalized method of moments; AR(2), Arellano–Bond test for second order autocorrelation.
*, **, and *** denote statistical significance at the 10%, 5%, and 1% levels, respectively. Robust standard error is reported in parenthesis. All regressions include time dummies.

Table 6 — Estimated results — Males.

Variable	Overweight ratios			Obesity ratios			Morbid obesity ratios		
	OLS	FE	GMM	OLS	FE	GMM	OLS	FE	GMM
Lag of dependent variable	1.021***	0.891***	0.985***	1.110***	1.053***	1.086***	1.410***	1.380***	1.394***
	(0.003)	(0.015)	(0.011)	(0.004)	(0.011)	(0.011)	(0.022)	(0.028)	(0.017)
LGDPPC	3.701***	1.603**	5.652***	1.224***	0.083	2.127***	0.027***	−0.044	0.056*
	(0.386)	(0.626)	(0.981)	(0.143)	(0.268)	(0.444)	(0.009)	(0.033)	(0.034)
LGDPPC^2	−0.211***	−0.082**	−0.317***	−0.068***	0.000	−0.119***	−0.001***	0.003	−0.003
	(0.022)	(0.039)	(0.056)	(0.008)	(0.017)	(0.026)	(0.001)	(0.002)	(0.002)
TRADE	0.087	0.121	−0.035	0.050	0.095	−0.022	0.012***	0.002	0.017
	(0.088)	(0.136)	(0.314)	(0.040)	(0.063)	(0.133)	(0.004)	(0.008)	(0.011)
URBAN	0.016***	0.082***	0.044***	0.005***	0.027***	0.014***	0.000***	0.001	0.000
	(0.002)	(0.010)	(0.007)	(0.001)	(0.005)	(0.002)	(0.000)	(0.001)	(0.000)
AR(2)			0.422			0.784			0.818
Hansen test			0.216			0.202			0.122
# of obs.	910	910	910	910	910	910	910	910	910
# of countries	130	130	130	130	130	130	130	130	130
R-squared	0.999	0.996		0.998	0.995		0.995	0.993	

LGDPPC, log of real GDP per capita; FLP, female labor participation; GINI, Gini index; URBAN, urban population; TRADE, trade openness; OLS, ordinary least squares; FE - Fixed effects; GMM, generalized method of moments; AR(2), Arellano—Bond test for second order autocorrelation. *, **, and *** denote statistical significance at the 10%, 5%, and 1% levels, respectively. Robust standard error is reported in parenthesis. All regressions include time dummies.

For the results of both sex in Table 5, the estimations show that the coefficients on LGDPPC are significantly positive and that those on squared LGDPPC are significantly negative for the OLS and system GMM estimations, regardless of the types of weight-related health status. Our analysis presents clear evidence supporting an inverted U-shaped Kuznets curve relationship between weight-related health status and real income per capita. For low-income countries, as incomes increase, the rates of overweight, obesity, and morbid obesity increase; thus, an increase in incomes raises the health risk. In contrast, for high-income countries, as incomes increase, the rates of overweight, obesity, and morbid obesity decrease;

thus, an increase in incomes reduces the health risk. A recent study on the case of the United States also recommends that improving people's income from low- to middle-income levels will help control the rising obesity trend in the US adult population.[43] Our system GMM estimators also show that the rates of overweight, obesity, and morbid obesity for both sex peak at the levels of real income per capita of approximately US$ 4600, 4000, and 4800, respectively (Table 8). It should be noted that the peak-out levels depend highly on empirical methods and model specifications, so that our estimated peak-out levels under the system GMM may not be precise but should be considered just a reference. Our results based on

Table 7 — Estimated results — Females.

Variable	Overweight ratios			Obesity ratios			Morbid obesity ratios		
	OLS	FE	GMM	OLS	FE	GMM	OLS	FE	GMM
Lag of dependent variable	1.027***	0.822***	1.024***	1.078***	0.951***	1.075***	1.221***	1.157***	1.219***
	(0.003)	(0.029)	(0.007)	(0.004)	(0.019)	(0.008)	(0.008)	(0.016)	(0.012)
LRGDPPC	2.247***	2.057***	3.360***	1.815***	0.547	2.462***	0.289***	0.095	0.375***
	(0.380)	(0.700)	(1.058)	(0.257)	(0.415)	(0.653)	(0.045)	(0.068)	(0.112)
LRGDPPC^2	−0.139***	−0.126***	−0.214***	−0.108***	−0.033	−0.152***	−0.017***	−0.005	−0.022***
	(0.022)	(0.045)	(0.064)	(0.015)	(0.027)	(0.039)	(0.003)	(0.004)	(0.006)
TRADE	0.425***	−0.263*	1.017***	0.281***	−0.054	0.451*	0.035***	−0.015	0.057
	(0.100)	(0.159)	(0.347)	(0.069)	(0.094)	(0.237)	(0.012)	(0.019)	(0.049)
URBAN	−0.012***	0.070***	−0.006	−0.004***	0.037***	0.002	−0.001**	0.005***	−0.000
	(0.002)	(0.013)	(0.006)	(0.001)	(0.007)	(0.004)	(0.000)	(0.001)	(0.001)
AR(2)			0.372			0.649			0.453
Hansen test			0.245			0.225			0.223
# of obs.	910	910	910	910	910	910	910	910	910
# of countries	130	130	130	130	130	130	130	130	130
R-squared	0.997	0.987		0.996	0.988		0.994	0.986	

LGDPPC, log of real GDP per capita; FLP, female labor participation; GINI, Gini index; URBAN, urban population; TRADE, trade openness; OLS, ordinary least squares; FE, fixed effects; GMM, generalized method of moments; AR(2), Arellano—Bond test for second order autocorrelation. *, **, and *** denote statistical significance at the 10%, 5%, and 1% levels, respectively. Robust standard error is reported in parenthesis. All regressions include time dummies.

Table 8 – System-GMM estimations.

Variable	Overweight			Obesity			Morbid obesity		
	Both sex	Male	Female	Both sex	Male	Female	Both sex	Male	Female
Lag of dependent variable	1.006***	0.985***	1.024***	1.074***	1.086***	1.075***	1.083***	1.394***	1.219***
	(0.009)	(0.011)	(0.007)	(0.010)	(0.011)	(0.008)	(0.009)	(0.017)	(0.012)
LGDPPC	4.403***	5.652***	3.360***	2.184***	2.127***	2.462***	1.652***	0.056*	0.375***
	(1.017)	(0.981)	(1.058)	(0.542)	(0.444)	(0.653)	(0.412)	(0.034)	(0.112)
LGDPPC^2	−0.261***	−0.317***	−0.214***	−0.132***	−0.119***	−0.152***	−0.097***	−0.003	−0.022***
	(0.060)	(0.056)	(0.064)	(0.032)	(0.026)	(0.039)	(0.024)	(0.002)	(0.006)
TRADE	0.361	−0.035	1.017***	0.159	−0.022	0.451*	0.250	0.017	0.057
	(0.311)	(0.314)	(0.347)	(0.154)	(0.133)	(0.237)	(0.257)	(0.011)	(0.049)
URBAN	0.018***	0.044***	−0.006	0.011***	0.014***	0.002	0.005*	0.000	−0.000
	(0.006)	(0.007)	(0.006)	(0.003)	(0.002)	(0.004)	(0.003)	(0.000)	(0.001)
AR(2)	0.251	0.422	0.372	0.257	0.784	0.649	0.292	0.818	0.453
Hansen test	0.281	0.216	0.245	0.119	0.202	0.225	0.246	0.122	0.223
# of obs.	910	910	910	910	910	910	896	910	910
# of countries	130	130	130	130	130	130	130	130	130
Peak-Out level of GDPPC	4627	7469	2530	4023	7434	3272	4795	-	4700

LGDPPC, log of real GDP per capita; FLP, female labor participation; GINI, Gini index; URBAN, urban population; TRADE, trade openness; OLS, ordinary least squares; GMM, generalized method of moments AR(2), Arellano–Bond test for second order autocorrelation.
Notes: *, **, and *** denote statistical significance at the 10%, 5%, and 1% levels, respectively. Robust standard error is reported in parenthesis. All regressions include time dummies. No peak-out level of GDPPC is shown in the morbid obesity equation for males because the coefficient on squared LGDPPC is insignificant.

country-level data are partly consistent with the previous findings that income per capita is positively related to BMI up to US$ 3000, with no significant relationship beyond this level,[31] that both overweight and obesity are non-linearly related to income per capita,[44] and that there is an empirical basis for the obesity Kuznets curve for white females within the United States.[25]

Our models cannot discuss possible links between the characteristics of individuals and the obesity epidemic because our sample accounts only for aggregate features at the country level. However, our analysis confirms some important national trends of the income-obesity relationship, which could help regulators plan and implement sound health policies to reduce people's health risk as well as the financial burden associated with healthcare costs for individuals and governments. The policy implications suggest that a strong initiative for health policy targeting obesity prevention is required, particularly for middle-income countries, many of which are currently experiencing high economic growth.

To check possible gender differences in the income-obesity relationship, we estimate the empirical models for each

Table 9 – Models with additional control variables, FLP (system-GMM estimation).

Variable	Overweight			Obesity			Morbid obesity		
	Both sex	Male	Female	Both sex	Male	Female	Both sex	Male	Female
Lag of dependent variable	1.004***	0.991***	1.019***	1.074***	1.082***	1.072***	1.073***	1.382***	1.216***
	(0.011)	(0.012)	(0.010)	(0.012)	(0.014)	(0.013)	(0.012)	(0.016)	(0.015)
LGDPPC	3.876***	5.412***	3.371**	1.694**	1.881***	2.556***	2.246***	0.043	0.396**
	(1.159)	(1.303)	(1.335)	(0.675)	(0.566)	(0.805)	(0.571)	(0.036)	(0.154)
LGDPPC^2	−0.239***	−0.320***	−0.220***	−0.105***	−0.111***	−0.163***	−0.136***	−0.002	−0.024***
	(0.069)	(0.076)	(0.081)	(0.040)	(0.033)	(0.048)	(0.034)	(0.002)	(0.009)
TRADE	1.100***	0.977**	1.455***	0.412*	0.001	1.066***	0.535*	0.010	0.160**
	(0.386)	(0.391)	(0.446)	(0.237)	(0.236)	(0.363)	(0.274)	(0.023)	(0.081)
URBAN	0.009	0.035***	−0.012	0.009*	0.020***	−0.005	0.006	0.001**	−0.001
	(0.009)	(0.008)	(0.008)	(0.005)	(0.005)	(0.006)	(0.004)	(0.000)	(0.001)
FLP	−1.817	−1.805	−0.857	−0.401	−0.387	−0.921	−0.689	0.027	−0.238
	(1.381)	(1.368)	(1.565)	(0.673)	(0.745)	(1.138)	(0.582)	(0.047)	(0.152)
AR(2)	0.635	0.869	0.643	0.968	0.793	0.320	0.253	0.593	0.621
Hansen test	0.246	0.394	0.282	0.168	0.220	0.187	0.130	0.172	0.182
# of obs.	630	630	630	630	630	630	630	630	630
# of countries	126	126	126	126	126	126	126	126	126

LGDPPC, log of real GDP per capita; FLP, female labor participation; GINI, Gini index; URBAN, urban population; TRADE, trade openness; OLS, ordinary least squares; GMM, generalized method of moments; AR(2), Arellano–Bond test for second order autocorrelation.
*, **, and *** denote statistical significance at the 10%, 5%, and 1% levels, respectively. Robust standard error is reported in parenthesis. All regressions include time dummies.

Table 10 — Models with additional control variables, GINI (system-GMM estimation).

Variable	Overweight			Obesity			Morbid obesity		
	Both sex	Male	Female	Both sex	Male	Female	Both sex	Male	Female
Lag of dependent variable	0.982***	0.995***	1.006***	1.058***	1.087***	1.054***	1.057***	1.361***	1.211***
	(0.013)	(0.013)	(0.014)	(0.013)	(0.012)	(0.013)	(0.012)	(0.026)	(0.018)
LGDPPC	5.796***	7.560***	3.778***	2.363***	2.152***	2.787***	2.370***	−0.022	0.510***
	(1.274)	(1.189)	(1.209)	(0.722)	(0.548)	(1.016)	(0.733)	(0.073)	(0.167)
LGDPPC^2	−0.334***	−0.432***	−0.230***	−0.135***	−0.121***	−0.165***	−0.135***	0.002	−0.030***
	(0.072)	(0.068)	(0.069)	(0.043)	(0.033)	(0.058)	(0.043)	(0.004)	(0.010)
TRADE	0.251	0.173	0.327	0.003	0.095	0.106	0.066	−0.008	0.011
	(0.470)	(0.492)	(0.443)	(0.253)	(0.226)	(0.301)	(0.297)	(0.030)	(0.068)
URBAN	0.027***	0.036***	0.005	0.012***	0.014***	0.008	0.013***	0.001**	0.002
	(0.009)	(0.011)	(0.008)	(0.005)	(0.003)	(0.006)	(0.004)	(0.001)	(0.001)
GINI	0.032***	0.021*	0.045***	0.020***	0.009*	0.032***	0.020***	0.001*	0.002
	(0.010)	(0.011)	(0.012)	(0.007)	(0.006)	(0.009)	(0.007)	(0.001)	(0.002)
AR(2)	0.587	0.247	0.791	0.394	0.449	0.555	0.721	0.397	0.513
Hansen test	0.371	0.323	0.390	0.411	0.309	0.339	0.377	0.366	0.586
# of obs.	356	356	356	356	356	356	356	356	356
# of countries	110	110	110	110	110	110	110	110	110

LGDPPC, log of real GDP per capita; FLP, female labor participation; GINI, Gini index; URBAN, urban population; TRADE, trade openness; OLS, ordinary least squares; GMM, generalized method of moments; AR(2), Arellano—Bond test for second order autocorrelation.

*, **, and *** denote statistical significance at the 10%, 5%, and 1% levels, respectively. Robust standard error is reported in parenthesis. All regressions include time dummies.

gender. The estimated results of the system GMM estimators, shown in Tables 6 and 7, generally confirm the existence of the obesity Kuznets curve for males and females, except for the case of the morbid obesity rates for males. In addition, Table 8 shows that the system GMM estimations of the peak-out levels of real income per capita. Although we admit that our estimated peak-out levels should be considered just a reference, as mentioned in the previous discussion, the estimated peak-out levels are consistently higher for males than

for females, irrespective of the choices of obesity measures and empirical methods (the OLS, fixed effects, and system GMM estimations). As an economy develops, the weight-related health status of females tends to peak at the earlier stage of development than it does for males. Females and males face different types of social pressure in regard to being overweight. Since females are likely to experience more social pressure over obesity than males, their concern regarding overweight is relatively large.[25,45] Even with a similar body

Table 11 — Models with all additional control variables, FLP, and GINI (system-GMM estimation).

Variable	Overweight			Obesity			Morbid obesity		
	Both sex	Male	Female	Both sex	Male	Female	Both sex	Male	Female
Lag of dependent variable	0.992***	0.997***	1.002***	1.069***	1.097***	1.059***	1.059***	1.369***	1.220***
	(0.013)	(0.014)	(0.017)	(0.012)	(0.015)	(0.016)	(0.015)	(0.030)	(0.017)
LGDPPC	5.307***	7.200***	3.567***	2.221***	2.323***	2.480***	2.358***	−0.015	0.468***
	(1.164)	(1.825)	(0.938)	(0.618)	(0.715)	(0.605)	(0.848)	(0.093)	(0.159)
LGDPPC^2	−0.313***	−0.415***	−0.221***	−0.130***	−0.134***	−0.151***	−0.135***	0.002	−0.027***
	(0.065)	(0.103)	(0.053)	(0.035)	(0.040)	(0.035)	(0.050)	(0.006)	(0.009)
TRADE	0.238	0.216	0.359	0.245	0.202	0.243	0.114	0.003	0.074
	(0.421)	(0.431)	(0.378)	(0.271)	(0.245)	(0.286)	(0.262)	(0.037)	(0.061)
URBAN	0.023**	0.040***	−0.003	0.008	0.014***	0.002	0.013***	0.001*	0.000
	(0.010)	(0.010)	(0.009)	(0.005)	(0.004)	(0.008)	(0.004)	(0.001)	(0.001)
FLP	−0.086	1.159	−1.303	−0.159	0.523	−0.821	−0.135	0.089	−0.065
	(1.004)	(1.165)	(1.203)	(0.510)	(0.559)	(1.119)	(0.857)	(0.068)	(0.148)
GINI	0.036***	0.020*	0.047***	0.021***	0.009	0.033***	0.017**	0.002**	0.003
	(0.012)	(0.012)	(0.016)	(0.007)	(0.006)	(0.010)	(0.007)	(0.001)	(0.002)
AR(2)	0.620	0.190	0.538	0.618	0.532	0.906	0.870	0.430	0.530
Hansen test	0.154	0.188	0.232	0.318	0.183	0.220	0.235	0.179	0.293
# of obs.	356	356	356	356	356	356	356	356	356
# of countries	110	110	110	110	110	110	110	110	110

LGDPPC, log of real GDP per capita; FLP, female labor participation; GINI, Gini index; URBAN, urban population; TRADE, trade openness; OLS, ordinary least squares; GMM, generalized method of moments; AR(2), Arellano—Bond test for second order autocorrelation.

*, **, and *** denote statistical significance at the 10%, 5%, and 1% levels, respectively. Robust standard error is reported in parenthesis. All regressions include time dummies.

weight, females tend to make more efforts to keep a slimmer body weight since they are dissatisfied with their weight.[46] Thus, as incomes increase, weight-related health status peaks at a lower income level for females than for males.

For the robustness checks, Tables 9 and 10 show the results of the models including additional control variables, FLP and GINI, respectively, and Table 11 presents the results of the models including both FLP and GINI. The results are still consistent with our baseline findings supporting the existence of the obesity Kuznets curve. Concerning other control variables, the results of the system GMM estimations confirm a positive relationship between urbanization (URBAN) and weight-related health status, particularly for both sex and males, which suggests that urbanization increases the obesity epidemic by allowing urban males to improve their access to food and to have a sedentary life. In addition, our analysis verifies a positive relationship between obesity rates and the GINI, which implies that income inequality increases the obesity epidemic. However, our estimations generally present less clear evidences of the links of the obesity epidemic with TRADE and FLP.

Discussion

The obesity epidemic has been recognized as a global pandemic disease, but its extent differs substantially across countries. Among various socio-economic factors, economic development can be considered a crucial factor of such international variation. This study has examined the relationship between economic development and weight-related health status, which is measured by the rates of overweight, obesity, and morbid obesity, over 130 countries during the 5-year interval period from 1975 to 2010. The estimation has shown a clear pattern of the obesity Kuznets curve. For low-income countries, as incomes increase, weight-related health status deteriorates with a high health risk. In contrast, for high-income countries, as incomes increase, weight-related health status improves with the reduction of the health risk. Our analysis supports the argument that middle-income countries, many of which are currently enjoying high economic growth, may be in danger of damage to people's health and the related financial burden, requiring a strong initiative for health policy targeting obesity prevention. In addition, the results have suggested different types of social pressure in regard to being overweight between males and females, i.e. concern regarding overweight is larger for females than for males since females are likely to experience more social pressure over obesity than males.

Our study has several limitations. First, this study has assumed that BMI reflects an individual's health status. However, it may not be the best measure for capturing an individual's health status because of its failure to measure body fat and muscle. Second, it is acknowledged that the relationship between income and health depends on changes in poverty and inequality in a more complex manner. Our simple empirical models may not evaluate such a relationship extensively, so that more careful empirical analysis should be required to verify the obesity Kuznets curve. Third, concerning the methodological issues, the system GMM estimations we have applied in this study help capture dynamic effects over time that relate

to the potential recursive association. However, this method cannot solve all endogeneity issues, such as omitted variable problems. Although we admit these limitations, our study focusing on international differences would still contribute to the understanding of current situations and trends of the obesity epidemic in relation to economic development.

Author statements

Ethical approval

None sought. All data used in this study are at the country-level and are obtained from the open source.

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Competing interests

None declared.

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