National income and macro-economic correlates of the double burden of malnutrition: an ecological study of adult populations in 188 countries over 42 years

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Summary

Background The double burden of malnutrition (DBM) represents a growing global challenge with adverse health and economic consequences. We aimed to investigate the associative roles of national income (gross domestic product per capita [GDPPC]) and macro-environmental factors on the DBM trends among national adult populations.

Methods In this ecological study we assembled extensive historical data on GDPPC from the World Bank World Development Indicators database and population-level DBM data of adults (aged ≥18 years) from the WHO Global Health Observatory database in 188 countries over 42 years (1975–2016). In our analysis, a country was considered to have the DBM in a year when adult overweight (BMI ≥25·0 kg/m²) and underweight (BMI <18·5 kg/m²) prevalence was each 10% or more in that year. We used a Type 2 Tobit model to estimate the association of GDPPC and selected macro-environmental factors (globalisation index, adult literacy rate, female share in the labour force, share of agriculture in the national gross domestic product [GDP], prevalence of undernourishment, and percentage of principal display area mandated to be covered by health warnings on cigarette packaging) with DBM in 122 countries.

Findings We find a negative association between GDPPC and the likelihood of a country having the DBM. However, conditional on its presence, DBM level exhibits an inverted-U shaped association with GDPPC. We found an upward shift in DBM levels from 1975 to 2016 across countries at the same level of GDPPC. Among the macro-environmental variables, share of females in the labour force and share of agriculture in the national GDP are negatively associated with DBM presence in a country, whereas the prevalence of undernourishment in the population is positively associated. Further, globalisation index, adult literacy rate, share of females in the labour force, and health warnings on cigarette packaging are negatively associated with DBM levels in countries.

Interpretation DBM level in national adult populations rises with GDPPC until US$11 113 (in 2021 constant dollar terms) and then starts declining. Given their current GDPPC levels, most low-income and middle-income countries are thus unlikely to have a decline in the DBM levels in the near future, ceteris paribus. Those countries will also be expected to experience a higher DBM level at similar levels of national income than were historically experienced by the current high-income countries. Our findings point to a further intensification of the DBM challenge in the near future for the low-income and middle-income countries as they continue to have income growth.

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Introduction

The double burden of malnutrition (DBM) refers to the coexistence of undernutrition and overweight or obesity in a society.[1,2] The scope of the DBM is broad, with undernutrition encompassing the problems of stunting, wasting, micro-nutrient deficiencies, and underweight at one end; and overweight and obesity at the other end.[1,2] From a societal incidence perspective, the DBM manifests at three distinct levels.[1,2] Firstly, the DBM can occur at the individual level with the coexistence of two or more types of malnutrition, or of development of multiple types over a person's lifetime. Secondly, the DBM can manifest at the household level with multiple household members affected by different forms of malnutrition. Finally, the DBM can occur at the population level with both undernutrition and overweight or obesity prevalent in the same community, region, or nation. At individual and household levels, the DBM can be transitory; for example, underweight members of a household could gain weight over time.[3] However, at the population level, the DBM is often a more persistent phenomenon as individuals recovering from one form of malnutrition are replaced by other individuals with malnutrition.[3]

The DBM is widespread. In 2016, there were more than 1·9 billion adults who were overweight globally, of whom more than 670 million were obese, and over 480 million adults were underweight.[1,4,5] The DBM has clinically significant negative consequences for morbidity and mortality, health-care costs, educational outcomes (eg, school dropout), social inclusion, and productivity (eg, premature mortality and absenteeism). Although

Research in context

Evidence before this study

A systematic review of the extant literature was conducted to identify published studies on trends, correlates, consequences, and policy implications of the double burden of malnutrition (DBM). We searched PubMed and Web of Science using the terms "Double Burden of Malnutrition", "Double Burden Nutrition", "DBM Nutrition" , "Overweight Obesity National Income", and "Underweight National Income" for studies in English published from database inception up to July 29, 2021. In the context of our study, the most relevant research stream concerns the macroeconomic correlates of DBM trends. Several studies have investigated the association between national income and household-level DBM. In contrast, very few studies have focused on the association between national income levels and population-level DBM. Moreover, the few existing studies are limited in their scope to specific population sub-groups (eg, women), specific regions (eg, south Asia, Africa, and low-income and middle-income countries), and shorter time-period of analysis. However, to gain in-depth policy-relevant insights, it is important to understand the association of national income and other policy driven factors with different manifestations of the DBM, including population-level DBM. Additionally, widespread differences across countries (in multiple facets such as body composition, food habits, and macro-environmental factors) as well as over time (due to differences in income and demographic trajectories, globalisation trends, and policies etc) warrant investigating such associative relationships through the use of cross-sectional data across a large number of countries with substantial longitudinal data for each country to gain statistically robust insights. However, such insights into the associative relationship between national income levels and population-level DBM remain scant in the extant literature.

Added value of this study

In this study we investigate, using historical data, how increasing national affluence can alter the association between the DBM and national per capita income. We specifically investigate whether past empirical evidence points to a rising DBM as a kind of negative externality from national per capita income growth. If so, whether there is evidence of a threshold income level beyond which the DBM begins to decline as a kind of positive externality from income growth. If so, what is that threshold range? Given the policy significance of both economic growth and the DBM these are important questions.

We specifically focused on the most common form of the DBM —simultaneous prevalence of underweight and overweight—in adults (aged ≥18 years) for two important reasons. First, adults represent by far the largest population group—about 70% of the current global population. Second, one constraint faced in empirical research on the DBM is limited data availability, which in turn limits the generalisability of research findings. Our approach enabled us to assemble a comprehensive dataset covering 188 countries and a long time-period (1975–2016). A combination of cross-sectional data across many countries with substantial longitudinal data for each country made our dataset especially suited for statistically robust empirical analysis of the associative relationship between national income and population-level DBM.

We used a Type 2 Tobit model to study the correlates of the DBM presence in a country as well as the DBM level conditional on its presence. Complementing extant research, our study presents important but hitherto unexplored insights in the form of statistical estimates of the associative roles of national income levels on the evolving DBM trends among national adult populations. The insights add value to better inform and guide coordinated multi-sectoral policy initiatives in the context of the UN's Sustainable Development Goals for ending all forms of malnutrition and ensuring healthy lives and wellbeing for all.

Implications of all the available evidence

Our findings indicated that adult population-level DBM rises with national per capita income until a threshold income level of about US$11 113 in 2021 constant dollar terms, and then starts declining. However, most low-income and middle income countries (LMICs) are currently well below this estimated income threshold and are thus likely to witness a continued rise in the DBM levels in the near future, ceteris paribus. Further, there was an upward shift in the DBM levels over time for the same level of gross domestic product per capita. This finding implies that current LMICs are experiencing higher DBM levels than what was experienced by their counterparts in the past at a similar stage of economic development (ie, at a similar level of gross domestic product per capita). In other words, the lower-income countries are presently facing a de facto double jeopardy: a higher DBM challenge, but with lower resource capabilities to address it. Taken together, our findings point to a further intensification of the DBM challenge in the near future for LMICs as they continue to increase national income. As such, the findings underscore the crucial need for urgent and coordinated multi-sectoral policy initiatives to break or at least attenuate the positive association between the DBM level and income growth when income is still below the threshold range identified here.

accurate estimates of the economic costs of the DBM remain a challenge, one study[6] estimates that the DBM cost 1% (China) and 2% (India) of respective national gross domestic products (GDPs) in the early 2000s and could reach 9% of GDP in China by 2025.

Because of its widespread incidence and enormous costs for health and the economy, the DBM remains a top priority challenge in the global public health area.[1] There is an increasing recognition that the two dimensions of the DBM potentially share common

drivers, such as early-life nutrition, food environments, and socioeconomic factors.[7] Treating the DBM as a single issue with common drivers could result in more focused, concerted, efficient, and effective policies and programmes to tackle it, and also mitigate the risk of increasing one type of malnutrition when addressing the other.

To advance coordinated policies and programmes for addressing the DBM, understanding its contemporaneous associations with other policy driven factors is of vital importance. At a country level, one such factor is economic affluence, typically measured by national per capita income. An aspirational goal for most countries is continued growth in national per capita income. This societal goal raises the questions: what does historical data tell us about the nature of the association between the DBM in a country and its national per capita income? Specifically, do they point to a rising DBM as a kind of negative externality from national per capita income growth? If so, do we see evidence of a threshold income level beyond which the DBM in fact declines as a kind of positive externality upshot from income growth? If so, what is that threshold level?

A large volume of research has delved into the trends, correlates, consequences, and policy implications of the DBM.[2,7–18] However, very few studies have focused on the association between national income and population-level DBM, and these studies are limited in their scope to specific population sub-groups (eg, women), specific regions (eg, south Asia), and limited time-periods of analysis.[9–14] Additionally, widespread differences across countries (in body composition, food habits, and cultural and environmental factors, etc)[19,20] as well as over time (in income, demographic and globalisation trajectories, and policies, etc)[2,13] warrant investigating associative relationships through the use of cross-sectional data across a large number of countries with substantial longitudinal data for each country to gain statistically robust insights. This is the key contribution of this study.

Here, we aim to investigate the associative roles of national income levels and macro-environmental factors on the most common form of the DBM in terms of the coexistence of underweight and overweight prevalence among adults, who account for about 70% of the global population.[21] We aim to assemble a comprehensive dataset covering the DBM in 188 countries and macro-environmental variables in 122 countries over a long time period (42 years, 1975–2016), which will enable us to undertake a statistically robust empirical analysis and to offer novel and generalisable insights into the nature and dynamics of the concomitant association between national income and DBM trends among adult population groups. Such insights stand to better inform and guide policy initiatives to address the DBM challenge in the context of achieving the targets of the Decade of Action on Nutrition and the Sustainable Development Goals of the UN.[1]

Methods

Data

In this ecological study we assembled data from multiple sources, as detailed in the appendix (p 6). Specifically, we collected DBM data (extracted by DT) from the WHO Global Health Observatory database.[22] Although there is no consensus definition of the DBM,[9,23] in the existing literature population-level DBM is most frequently assessed using the coexistence of overweight or obesity and thinness, wasting, or underweight.[2,9,14,23] Given our focus on adult population, we captured the two dimensions of the DBM using annual, age-standardised, percentage prevalence data on adults (aged ≥18 years) who are underweight (BMI <18·5 kg/m²) or overweight (BMI ≥25·0 kg/m²) from 1975 to 2016 for each analysed country. In our analyses, a country was considered to have the DBM in a year when adult overweight and underweight prevalence was each 10% or more in that year.[9] Contingent on a country having the DBM as per this criterion, we defined the country's DBM level as the sum of adult overweight and underweight prevalence.

See Online for appendix

We obtained data on the annual national income (gross domestic product per capita [GDPPC]) in constant 2010 US$ for each country from 1975 to 2016 from the World Bank World Development Indicators database (data extracted by SS).[21] We investigated the association of the DBM with the following six country-specific macro-environmental variables: globalisation index, adult literacy rate, female share in the labour force, share of agriculture in the national GDP, prevalence of undernourishment (which is measured as the percentage of population whose food intake is insufficient to meet dietary energy requirements continuously), and percentage of principal display area mandated to be covered by health warnings in the front and back of cigarette packaging as a proxy for the existence of policies towards combatting non-communicable diseases (NCDs). We selected each of the macro-environmental variables based on the following considerations: the existing literature[2,10,13,20] identified it as a possible risk factor for underweight or overweight, or both, and data were available for at least 120 countries in our sample. The data for the macro-environmental variables came from the KOF index of globalisation,[24] The WHO Global Health Observatory database,[22] and the World Bank World Development Indicators database.[21]

Empirical model

Because the DBM level is observed only for those countries that meet our threshold for the DBM, we use a Type 2 Tobit model[25] to estimate the association of

GDPPC and macro-environmental variables with the DBM level (DBM_level), conditional on the DBM presence (DBM_presence=1) in a country (c) in a year (t):

$$\text{DBM\_presence}_{ct}=\begin{cases}1 & \text{if } y_{1ct}>0\\ 0 & \text{if } y_{1ct}\le 0\end{cases}$$

$$\text{DBM\_level}_{ct}=\begin{cases}y_{2ct} & \text{if } y_{1ct}>0\\ 0 & \text{if } y_{1ct}\le 0\end{cases}$$

where

$$y_{1ct}=\alpha_1+\beta_1\text{GDPPC}_{ct}+\gamma_1\text{Macro}-\text{environment}_c+\lambda_1\text{Region}_c+\theta_1\text{Time\_period}_t+\varepsilon_1$$

and

$$y_{2ct}=\alpha_2+\beta_2\text{GDPPC}_{ct}+\gamma_2\text{Macro}-\text{environment}_c+\theta_2\text{Time\_period}_t+\varepsilon_2$$

α_1 and α_2 capture the intercept, β_1 and β_2 capture the coefficient of GDPPC, γ_1 and γ_2 are vectors that capture the coefficients of the macro-environmental variables, λ_1 is a vector that captures the coefficients of the region fixed effects, and θ_1 and θ_2 are vectors that capture the coefficients of time period fixed effects in the DBM presence and level equation, respectively. ε_1 and ε_2 are normally distributed error terms and are assumed to be correlated. y_{1ct} is a latent variable. We observe the DBM_presence (outcome) when the latent variable y_{1ct} exceeds the threshold 0. y_{2ct} indicates the DBM level when the DBM is present. The explanatory variables in the DBM_presence equation include GDPPC, macro-environmental variables, region fixed effects (categorical variables representing east Asia, south Asia, Latin America, Middle East and north Africa, and sub-Saharan Africa), and time-period fixed effects (categorical variables representing decades 1985–94, 1995–2004, 2005–14, and 2015 onwards). The explanatory variables in the DBM_level equation include all these variables, other than region fixed effects and the prevalence of undernourishment in the population, which has been excluded for statistical identification purposes. We tested for potential non-linear relationship between the DBM level and GDPPC by estimating a model with both GDPPC and the square of GDPPC terms as independent variables in the DBM level equation, and used model fit criterion (Akaike information criterion) to assess the best fitting model. The parameters in the DBM presence equation are estimated using probit model. The parameters in the DBM level equation are estimated using maximum likelihood, after including the inverse Mills ratio (calculated from the estimates of the DBM presence equation) as an additional regressor. Sample selection bias was assessed for using the coefficient of the inverse Mills ratio. Model specification and estimation are discussed in detail in the appendix (p 1). We assessed the robustness of the Tobit model results by (1) using purchasing power parity adjusted GDPPC as the measure of national income, (2) using alternate thresholds for defining the DBM presence (≥7%, ≥9%, ≥10%, and ≥11% for underweight and ≥9%, ≥10%, ≥11%, ≥15%, and ≥20% for overweight), (3) controlling for inequality within countries by use of the Gini index, and (4) using an extended sample of 142 countries with the DBM (appendix p 4).

Role of the funding source

There was no funding source for this study.

Results

We first analysed the trends in DBM presence by plotting the proportion of 188 countries over 42 years (1975–2016) that had the DBM, underweight, and overweight burden separately over time (figure 1). DBM presence exhibited an inverted-U shape trend. The proportion of countries that had the DBM increased from 23·4% (44/188) in 1975 to 33·5% (63/188) in 1996, and then declined to 21·3% (40/188) in 2016. Further, the increase in the DBM presence from 1975 to 1996 corresponds with increasing prevalence of overweight burden, and its subsequent decrease corresponds with decreasing prevalence of underweight burden among countries. Of the countries that had the DBM in 1975 and for which GDPPC data was available, 13·8% (four/29) were low-income, 27·6% (eight/29) were lower middle-income, 41·4% (12/29) were upper middle-income, and 17·2% (five/29) were high-income countries. By contrast, of the countries that had the DBM in 2016 and for which GDPPC data was available, 54·3% (19/35) were low-income, 40·0% (14/35) were lower middle-income, 5·7% (two/35) were upper middle-income, and none were high-income countries (World Bank's income grouping of countries is shown in the appendix [p 7]).

We then analysed the trends in the DBM levels by plotting the average DBM, underweight, and overweight levels (conditional on the DBM presence) across countries over time (figure 2). The mean DBM level exhibited a U-shaped trend over the studied time period with a decrease from 33·12% in 1975 to 31·32% in 1985, and then an increase to 38·55% in 2016. Correspondingly, the mean overweight level also exhibited a U-shaped trend, decreasing from 18·33% in 1975 to 15·09% in 1985 and then increasing to 25·11% in 2016. The trends in underweight levels remained relatively stable, and the trends in DBM levels closely resembled those of overweight levels over time.

Further, the share of overweight levels in the DBM has been increasing since 1990, indicating that the DBM is increasingly because of overweight (appendix p 3). Taken together, the time trends indicate that even as fewer countries have the DBM in the past two decades, they are facing higher DBM levels contingent on its presence, and the increasing DBM levels in the past two decades are predominantly driven by increases in overweight prevalence, particularly in lower-income countries.

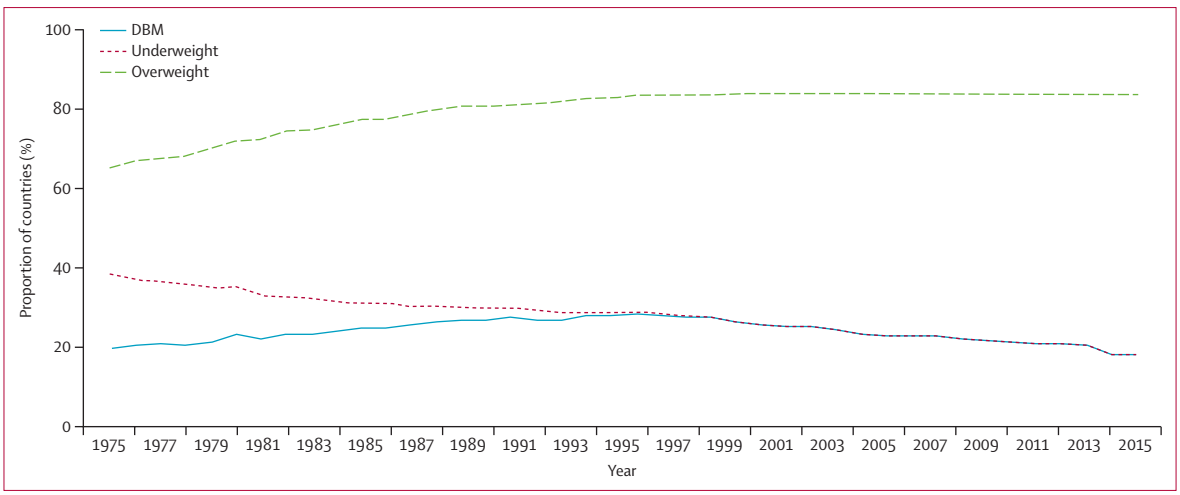

Figure 1: **Trends in the DBM presence among adult populations**
A country is considered as having an underweight or overweight burden in a year when the prevalence of adult population with underweight or overweight in the country is at least 10% for that year. A country is considered as having the DBM when the prevalence of underweight and overweight population in the country are both at least 10% in the year. The proportion of countries with the DBM, underweight burden, and overweight burden are calculated with respect to the 188 countries in our sample. DBM=double burden of malnutrition.

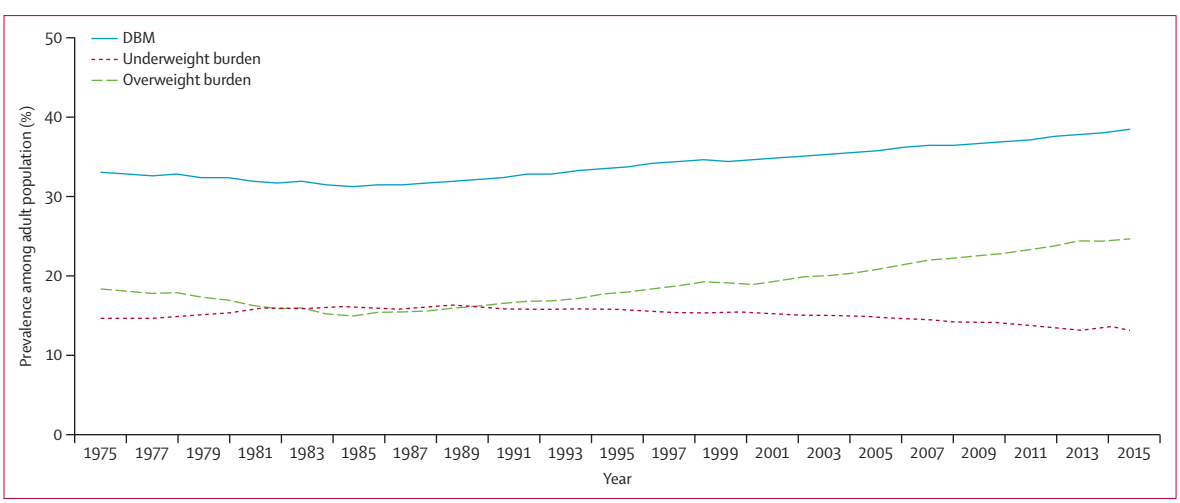

Figure 2: **Trends in the DBM level among adult populations**
Contingent on the DBM presence in a country in a particular year, its DBM level is the sum of underweight and overweight prevalence among its adult populations in that year. DBM=double burden of malnutrition.

We then analysed the association between national income (GDPPC) and the DBM (figure 3). Because the DBM presence is a binary variable, we grouped the GDPPC (across countries and years) into 65 distinct income groups in equal increments of US$1000 in each group, and plotted the proportion of country-level observations with the DBM (DBM presence=1) and the mean DBM level across countries with the DBM in each GDPPC group. The proportion of countries with the DBM decreases sharply as national incomes increase, suggesting a strong negative association between GDPPC and DBM presence. The mean DBM level exhibits an inverted-U association with GDPPC.

The association between GDPPC and DBM level exhibits an inverted-U type trend (figure 4). Additionally, a comparison of the 1975 and 2016 data points indicates a distinct upward shift in the DBM levels in 2016 for similar levels of GDPPC. In other words, low-income and middle-income countries, in more recent years, experience relatively higher DBM levels than were experienced by their counterparts in the past at similar levels of GDPPC.

For the Tobit model analyses, we excluded countries that had missing macro-environmental variables, resulting in a final sample of 122 countries. Model estimates for the DBM presence and level are shown in the table. We find a negative association between GDPPC and the DBM presence in a country, consistent with figure 3. Among the macro-environmental variables, share of females in the labour force and share of

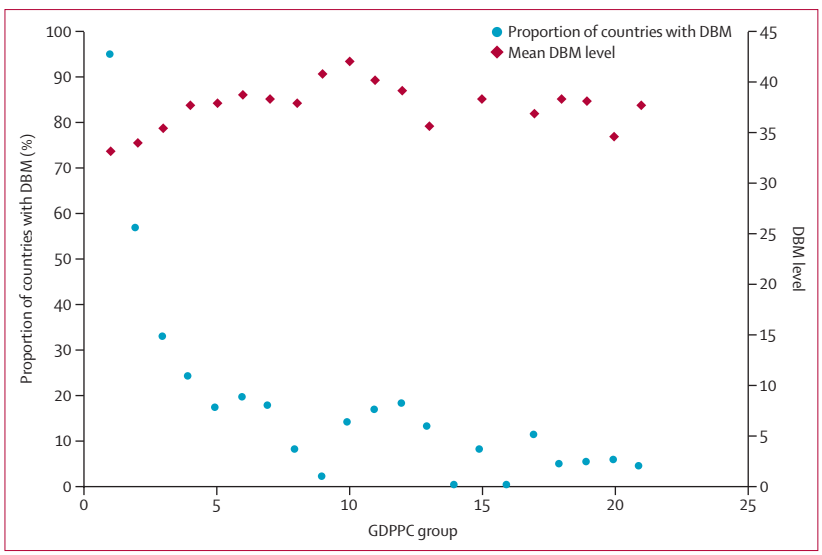

Figure 3: **The association between national income (GDPPC) and the DBM**
National incomes (GDPPC) across all study years are grouped into 65 groups in equal increments of US$1000. Data are shown for GDPPC of up to $25 000. The DBM presence for a country in a particular year is set to 1 when the prevalence of underweight and overweight in its adult population is at least 10% for each in that year. The proportion of countries having DBM is calculated with respect to the total number of countries in each GDPPC group. DBM=double burden of malnutrition. GDPPC=gross domestic product per capita.

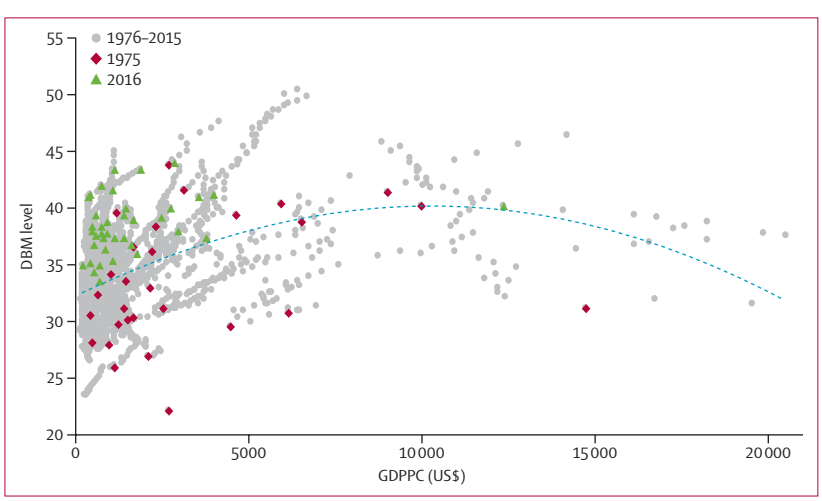

Figure 4: **The association between national income (GDPPC) and the DBM level**
GDPPC of countries are measured in constant 2010 US$. Contingent on DBM presence in a country in a particular year, its DBM level is the sum of underweight and overweight percentages among its adult populations in that year. Dashed line shows the GDPPC–DBM level association for the full data (1975–2016) using a quadratic trend line. DBM=double burden of malnutrition. GDPPC=gross domestic product per capita.

agriculture in the national GDP are negatively associated with the DBM presence in a country, whereas the prevalence of undernourishment in the population is positively associated. Further, the coefficient of the inverse Mills ratio (ρ) is significant, indicating the presence of sample selection bias and thereby justifying the use of the Type-2 Tobit model. Time-period fixed effects show that the DBM presence in countries increased in the first two decades (1985–2004) and then decreased. In terms of regions, countries in North America and Europe (reference group) had lower DBM presence compared with all other regions.

In the DBM level equation, we included both linear and quadratic GDPPC terms to statistically test the inverted-U shaped association between the GDPPC and DBM levels observed in our model free analysis. The coefficient estimates of both the linear and quadratic GDPPC terms were significant, and this model had a better fit (ie, lower Akaike information criterion) than the model with only linear term (appendix p 7), confirming that GDPPC indeed has an inverted-U shaped association with the DBM level. The inflection-point of this inverted-U association (calculated as the coefficient estimate of GDPPC / [2 × coefficient estimate of GDPPC^2]) is 0·8944. Thus, the DBM level in a country increases with its GDPPC up to $8944 ($11113 in 2021 constant dollar terms), and then decreases as GDPPC increases further.

In terms of macro-environmental variables, more globalised countries and countries that have higher adult literacy, higher share of women in the labour force, and policies to combat NCDs tend to have lower DBM levels. Time-period fixed effects show a monotonically increasing trend in the DBM levels after controlling for national income, consistent with our finding of an upward shift in the DBM levels over time.

We assessed the robustness of the Tobit model results, and the associations of GDPPC with the DBM presence and level are consistent across all analyses, supporting the robustness of our findings (appendix p 4).

Discussion

In this study, using extensive historical data across 188 countries over 42 years, we present important empirical insights into the association between country-level DBM among adults and various macro-environmental factors, especially national income level (GDPPC). Specifically, the time trend analysis shows an upward shift in the DBM levels over time for the same level of GDPPC, indicating that lower income countries are currently experiencing relatively higher DBM levels than were experienced by the poorer countries in the past. In other words, the current poorer countries are facing a double jeopardy: a higher level of DBM challenge, but with lower financial resource capabilities to address it.

From our Tobit model estimates, we find a negative association between the DBM presence and GDPPC, consistent with the rationale that increases in a country's income is accompanied by concurrent increases in the affordability of food and health care at individual and household levels, and resources to tackle malnutrition at the country level, which in turn reduces underweight prevalence and decreases the likelihood of the country having the DBM.[2,18]

However, contingent on the DBM presence, the DBM level exhibits an inverted-U shaped association with GDPPC. This finding is because overweight prevalence increases at a faster rate with GDPPC than the

corresponding decrease in underweight prevalence (as can be seen from the increasing share of overweight prevalence in the DBM over time in the appendix [p 3]), which could be due to the changes in food systems (eg, increased affordability of energy-dense processed foods and industrialisation of food systems) and lifestyle changes (eg, reduced manual labour, and sedentary lifestyles) that have accompanied national income growth.[2,18–20] However, the strength of this association is mitigated at higher income levels as continued economic growth also ushers in better resources and more effective policies, resulting in decreasing DBM levels at higher GDPPC.[20] Although our finding of an inverted-U association is in the context of adult population-level DBM, it adds systematic statistical evidence to the earlier exploratory finding of such an inverted-U shaped association between household-level DBM and national income by Popkin and Corvalan.[2] These findings offer cumulative evidence that increases in national income initially increase the DBM, but after a particular income threshold further increases tend to decrease the DBM.[26,27]

Among the macro-environmental variables, we find a negative association between the share of agriculture in the national GDP and DBM presence, consistent with the rationale that people in less agrarian, more industrialised countries have a more sedentary lifestyle, which increases malnutrition risks.[19,20] Share of females in the labour force is associated with lower DBM presence and level, consistent with existing findings that female workforce participation increases nutrition quality and food security through increasing household income and empowering women to become economically independent and take greater control over household decision making.[14]

We also find that more literate and globalised countries and those with policies for combatting NCDs tend to have lower DBM levels. Adult literacy, particularly among women, has been found to mitigate the DBM because of improved nutrition knowledge.[14] As for the effect of globalisation, while it can accentuate overweight prevalence,[19] it can also mitigate underweight prevalence through pathways such as increased access to food and nutrition information, thereby reducing the DBM levels.

From policy perspectives, an encouraging implication of our findings is that the DBM level rises with GDPPC until a particular threshold income level (about US$11113 in 2021 constant dollar), and then starts declining. However, the not so encouraging implication from our finding follows from the recognition that a vast majority of low-income and middle-income countries are currently far below the estimated threshold income level and are thus likely to witness a continued rise in their DBM levels in the near future. To make matters worse, our findings also indicate that these countries will have higher DBM levels at similar GDPPC levels than were historically experienced by the current developed countries. Taken together, our findings point to a further intensification of the DBM challenge in the near future for low-income and middle-income countries that are experiencing income growth. As such, our findings underscore the crucial need for urgent and coordinated multi-sectoral

	DBM presence	DBM level
Intercept	−58·345 (−59·035 to −57·655); p<0·0001	44·145 (42·411 to 45·879); p<0·0001
GDPPC	−0·785 (−0·991 to −0·580); p<0·0001	19·708 (17·556 to 21·860); p<0·0001
GDPPC²	..	−11·018 (−12·602 to −9·434); p<0·0001
Globalisation index	0·003 (−0·005 to 0·012); p=0·46	−0·170 (−0·194 to −0·146); p<0·0001
Adult literacy rate	−0·005 (−0·012 to 0·001); p=0·094	−0·020 (−0·032 to −0·009); p=0·0007
Female share in the labour force	−0·012 (−0·023 to −0·001); p=0·036	−0·101 (−0·122 to −0·080); p<0·0001
Share of agriculture in the national gross domestic product	−0·014 (−0·023 to −0·005); p=0·0030	−0·096 (−0·115 to −0·077); p<0·0001
Percentage of principal display area mandated to be covered by health warnings in the front and back of cigarette packaging	0·0003 (−0·003 to 0·003); p=0·83	−0·018 (−0·026 to −0·011); p<0·0001
Prevalence of undernourishment	0·026 (0·017 to 0·034); p<0·0001	..
Time period		
1985–94	0·115 (−0·046 to 0·276); p=0·16	1·629 (1·191 to 2·068); p<0·0001
1995–2004	0·226 (0·064 to 0·387); p=0·0062	4·499 (4·058 to 4·940); p<0·0001
2005–14	−0·123 (−0·284 to 0·038); p=0·14	6·332 (5·887 to 6·777); p<0·0001
2015–16	−0·472 (−0·755 to −0·189); p=0·0011	7·248 (6·446 to 8·050); p<0·0001
Region		
North America and Europe	1 (ref)	..
East Asia	59·159 (58·907 to 59·410); p<0·0001	..
South Asia	59·256 (59·080 to 59·431); p<0·0001	..
Latin America	57·550 (57·329 to 57·771); p<0·0001	..
Middle East and north Africa	57·630 (57·384 to 57·876); p<0·0001	..
Sub-Saharan Africa	59·887 (59·686 to 60·089); p<0·0001	..
Inverse Mills ratio, ρ	..	2·412 (1·958 to 2·866); p<0·0001
Log-likelihood	−1224	−3183
Akaike information criterion	2481	6395
Number of observations	4824	1347

Data are n (95% CI); p value unless stated otherwise. GDPPC is in $US10 000. The DBM presence for a country in a particular year is set to 1 when the prevalence of underweight and overweight in its adult population is at least 10% for each in that year. Contingent on DBM presence in a country in a particular year, its DBM level is the sum of underweight and overweight prevalence among its adult populations in that year. DBM=double burden of malnutrition. GDPPC=gross domestic product per capita

Table: **Associations of national income and macro-environments with the DBM**

policy interventions to break or at least attenuate the positive association between the DBM level and income growth when income is still below the threshold range. In this regard, double-duty[7,16] actions that target the common mechanisms that underlie both forms of malnutrition and are actuated by economic growth (such as transitions in food environments and overall unhealthy lifestyles)[2] could help mitigate the DBM without exacerbating the overweight burden. As higher female labour force participation and adult literacy are associated with lower DBM levels, empowering women through education and employment could also help mitigate the DBM.

Our study has a number of limitations, which present several important avenues for future research. First, as the DBM by definition implies burden from both the overweight and underweight dimensions of malnutrition, we used a 10% prevalence as threshold for both dimensions to identify whether a country experiences the DBM. We assessed the robustness of our findings using a wide range of thresholds for underweight (≥7%, ≥9%, ≥10%, and ≥11%) and overweight (≥9%, ≥10%, ≥11%, ≥15%, and ≥20%) prevalence. However, despite the wide range of thresholds, most countries in our sample exceed the overweight threshold since the mid 1990s. This limitation highlights the vital need for developing multidimensional measures to operationalise the DBM for various population groups.

Second, although we focused on adult overweight and underweight prevalence in this study, the DBM can manifest in other ways, such as micronutrient deficiencies and NCDs, as well as among other population groups such as children. It is important to analyse the trends and the macro-economic correlates of various manifestations of the DBM among different population groups to gain in-depth understanding of the DBM challenge.

Third, the aggregate country-level data in our study do not allow us to consider the patterns of DBM prevalence across population sub-groups within a country. It is also important to recognise that the effect of macro-environmental variables on the DBM could differ by subpopulation groups (eg. rich *vs* poor and men *vs* women)[13] and across countries at different income levels. Understanding such interaction effects is an interesting future research direction.

Fourth, although our model includes region and time-period fixed effects, it doesn't fully account for unobserved differences between countries or potential delayed effects of income changes on the DBM. Further, missing values in the data and the accuracy of the aggregate national-level data could have implications for our model estimates.

Lastly, although our findings help policymakers to better anticipate and plan for adverse DBM impacts that accompany economic growth in developing countries, it does not explore the underlying socioeconomic mechanisms that enable such adverse effects to unfold in the first place. An important future research imperative would be to analyse the socioeconomic mechanisms that underlie the DBM, and assess the relative efficacies of various policy recommendations that have been proposed by WHO Global NCD Action Plan,[28] Ending Childhood Obesity report,[29] and other expert reports[30] to essentially bypass the adverse public health impacts typically engendered by economic affluence.

Contributors

DT conceived the project. DT and SS designed the statistical analysis. SS compiled the data and performed the statistical analysis. SS, DT, and AN contributed to the interpretation of the results. SS and DT wrote the original draft of the manuscript. SS and AN wrote the revised draft of the manuscript. Both SS and AN have full access to the data, verified the data, reviewed the draft, and approved the decision to submit for publication.

Declaration of interests

We declare no competing interests.

Data sharing

All data used in this study have been compiled from publicly available databases from the World Bank, WHO, and KOF index of globalisation. Details of data sources are provided in the appendix (p 6).

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