Global Food Security

# Climate change and obesity: a global analysis

--Manuscript Draft--

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| **Manuscript Number:** | |
| **Article Type:** | IG000017:Invited research article |
| **Keywords:** | Obesity; BMI; climate change; temperatures |
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| **Suggested Reviewers:** | Ruopeng An<br>RUOPENG@WUSTL.EDU<br>His research interests cover the relation between ambient temperature and obesity.<br>Our manuscript quotes his researches several times. |
| | Claire Davis<br>cdavis74@jhu.edu<br>Her research activity, that we cite, looks at the effects of climate change on nutrition, a relation that we also try to explore in our analysis. |

Highlights:

- Obesity and climate change are co-existing pandemics, but rarely examined together
- Our analysis explores their relation on a global sample over 40 years
- A U-shaped curve characterizes the effects of temperatures on Body Mass Index
- This climate change-obesity raises food security concerns in developing countries
- A 1°C increase in temperatures leads to a 4% and 2% increase in children and women’s BMI

Manuscript title

# Climate Change and Obesity: A Global Analysis

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# Climate Change and Obesity: A Global Analysis

## Abstract

Climate change and obesity are two distinguished major concerns for policy makers globally, but can climate change be a driver of obesity? This is what this analysis tries to establish. To this extent, we exploit inter-annual variation of Body Mass Index (BMI) for children and adults for 134 countries over 39 years, to study to what extent variations in temperatures and precipitations have a causal effect on obesity. Using panel data econometrics and exploiting both within- and across-country variation in BMI, we uncovered a robust U-shaped relationship between temperature and the BMI of girls, boys and women, but failed to detect any significant effect of rainfalls. Our analysis also reveals that the impact of temperature on BMI, particularly for girls and women, is robust to the inclusion of other determinants of obesity stressed by the previous literature, suggesting that temperature has an independent direct effect on BMI.

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# 1. Introduction

The impact of climate change (CC) on mankind is being scrutinized by global scientists; medias are trying to increase people's awareness, but governments are more or less prone to incorporate CC in their political platforms.

The definition of CC is broad and ranges from the rise in temperatures and sea levels to the increased frequency in natural disasters and heat waves. Regardless of how one may depict it, the literature on the topic confirms that the threats of CC are indeed existential. Recently, Barreca et al. (2016) and Carleton et al. (2018) analysed the mortality consequences of CC and more frequent heat waves, a concern for both high- and low-income countries (Haines et al., 2006). CC also affects physical and mental health, and facilitates the spread of infectious diseases (McMichael et al., 2006), too. Among the different shades of health, obesity has recently become a global pandemic, co-occurring with undernutrition and CC (see Swinburn et al., 2019; Scrinis, 2020). Still, the effects of CC of obesity have not been thoroughly explored yet.

The literature on obesity drivers is abundant, stressing the existence of many concurring explanations for this phenomenon. One, undisputed transmission channel is a country level of development, with Gross-Domestic-Product, or GDP (e.g. Masood and Reidpath, 2017; Egger et al., 2012; Wells et al., 2012), urbanization (Abay and Amare, 2018), globalization (e.g. Oberlander et al., 2017; Costa-Font and Mas, 2016; Miljkovic et al., 2015; De Vogli et al., 2013; Hawkes, 2006), gender inequality and women empowerment, usually proxied by fertility rates (e.g. Beshara et al., 2010, Horning et al., 2017), being identified as relevant determinants. All these factors are in fact drivers of a complex phenomenon, known as nutrition transition (e.g., Popkin 2015), that takes populations from famine towards less healthy dietary patterns rich in sugar, saturated fats, and refined foods (Popkin and Gordon-Larsen, 2004), and that can trigger Non-Communicable Diseases (NCD), such as obesity and type 2 diabetes, already in early childhood (Abdullah, 2015; Bosu, 2015; Rivera et al., 2014).

Agriculture adapted to such a rapid diet shift, becoming an overhauled modern agricultural system, with increased availability and affordability of food and processed food (An et al., 2018b; Popkin and Reardon, 2018). On top of these demand and supply effects, diet shifts can be induced by agricultural productivity shocks following climate extreme events, that threaten agricultural production adding to the burden of malnutrition (e.g. Fanzo et al., 2018): on one side, people would opt for unhealthy processed food, thus increasing the probability of obesity (An et al., 2018b); on the other side, food insecure populations might experience nutrient deficiencies and undernutrition (Swinburn et al., 2019).

Clearly, nutrition transition cannot be entirely blamed for diet shifts. There is also a strong individual behavioural component that makes people engage in wrong habits, such as unhealthy food choices and reduced physical activities (see Zivin and Neidell, 2014), paving the way to obesity especially in hot and wet countries (Hobbs et al., 2019; Kowaleski-Jones et al., 2017; Garg et al., 2019; Heaney et al., 2019; Obradovich and Fowler, 2017; Bosu, 2015; Mchiza and Steyn, 2015; Stone et al., 2010). Individual factors favouring obesity can also be spotted in genetics: for instance, pollution induced genetic mutations (Jerrett et al., 2014; An et al., 2018a, b), genetic predisposition (Kowaleski-Jones et al., 2017; Liu et al., 2015; Kanter and Caballero, 2012; Norton and Han, 2008), and physiological processes, such as thermoregulation (Speakman, 2018). Last but not least, cultural heritage emerges as a latent predictor of obesity (e.g. Swinburn et al., 2019, Dioikitopoulos et al., 2020).

All these transmission channels have been proved to affect the Body Mass Index (BMI), i.e. the ratio between weight and squared height, which is one of the main proxies for obesity (e.g. Gutin, 2018), but very few contributions have investigated how climate variables can affect

BMI, weight gains, and ultimately obesity, as in Voss et al. (2013). In our analysis, we fill this gap by investigating how weather variables, namely temperature and precipitations, affect BMI, and to what extent their effects are independent of the introduction of other relevant transmission channels established by previous works. Since genetic mutations and predisposition are hard to establish in a cross-country study, we limit our analysis to directly observable channels, i.e. economic development, fertility rates, agricultural productivity, trade openness, and institutional quality. Thanks to the introduction of fixed effects, typical of panel data econometrics, we are also evaluating the existence of a direct and indirect CC-obesity nexus net of all those mainly time invariant country characteristics, such as culture, food habits, religion, and ethnicity among others.

Our analysis reveals that CC directly and indirectly affects BMI, with the effects being differentiated by gender and age, just like Carleton et al. (2018) reported for the CC-mortality picture. The effects of temperatures on BMI are U-shaped when it comes to children, girls, and women, while they are linear and negative for men. Last, we argue that the U-shaped impact emerging from our analysis is mostly threatening developing countries, which are the most vulnerable and exposed to the effects of CC, and whose BMI is fast approaching the obesity threshold (Popkin and Gordon-Larsen, 2004; Giuntella et al., 2018). Our estimated relationship shows that in developing countries a uniform increase of 1°C in temperature induces a 4 and 2% increase in the BMI of girls and women, respectively. Thus, global warming could represent an important threat for the obesity epidemic.

The paper is structured as follows: Section 2 describes the data used in the analysis and the empirical method; Sections 3 and 4 respectively present the results of the direct and indirect effects of CC on BMI; last, Section 5 discusses the results and draws the main conclusions.

# 2 Data and Method

## 2.1 Data

*Dependent variable.* To investigate the impact of CC on obesity, we use the BMI levels estimated by Abarca-Gómez et al. (2017 for 150 countries from 1975 to 2014, who, starting from the information contained in 2,416 population studies, retrieve mean BMI values and prevalence categories (severe, moderate and mild underweight, healthy weight, overweight but not obese, and obese), thus providing the first, comprehensive set of comparable estimates for adults and children. The paper pictures a dramatic, non-negligible scenario, with children's and adolescents' BMI rapidly increasing also in developing regions. Although under-nutrition is still a persistent issue especially in low-income countries, the restless, positive trend in children obesity is such that the number of overweight and obese children and adolescents is soon expected to surpass that of stunted children.

*Weather and climate variables.* To predict the effect of CC on obesity, we combine BMI data with the annual average temperature and precipitations data produced by the Climatic Research Unit (CRU) of the University of East Anglia (UEA), that are gridded historical datasets at 0.5° x 0.5° and derived from observational data. CRU provides quality-controlled temperature and rainfall, as well as other related information, including monthly and long-term historical climatologies. Temperature and precipitation data used in our analysis are based on monthly observations, averaged across the year and by country.

*Other controls.* To investigate the robustness of the climate-BMI nexus and to learn something about the underlying mechanisms, we also add control variables suggested by previous literature on BMI determinants. In particular, we introduce two economic indicators, GDP per capita (i.e., the ratio between the Expenditure-side real GDP at chained PPPs, in mil. 2011US$, and population), and trade-openness (i.e., imports plus exports divided by GDP), both derived from the Penn World Tables, to evaluate the impact of CC on obesity once economic development and economic globalization have been taken in due account. The literature on the topic has stressed that GDP per capita is indeed a very relevant transmission channel, not only on obesity per se (e.g. Masood and Reidpath, 2017; Egger et al., 2012; Wells et al., 2012), but also on nutritional quality in general (Oberlander et al., 2017). These studies suggest that countries at an early and intermediate stage of development experience a nutrition transition with a potentially dangerous shift in their dietary patterns (see also Jolliffe, 2011).

As for trade, the available evidence is highly controversial: despite the undisputed, positive role of globalization on obesity, it is yet to be established whether the real driver is cultural, social or economic globalization (Oberlander et al., 2017; Costa-Font and Mas, 2016; Miljkovic et al., 2015; Hawkes, 2006).

Since obesity, and nutrition in general, cannot be examined without considering a country agricultural system, especially when looking at rural and developing one, we also include agricultural productivity, measured as the ratio of the value of agricultural production at constant (international) prices and agricultural land, both variables being taken from FAO data. This variable could be in fact an important mediating factor in exploring the climate-obesity nexus, simply because agriculture is the sector most affected by CC and weather shocks (e.g., Schlenker and Lobell, 2010), with developing countries being more at risk than developed ones in this respect (Dell et al., 2012). A positive effect on obesity emerges in Schmidhuber and Shetty (2005). In line with the main arguments of our paper, this effect has been detected not only in industrialized countries, but also in developing countries afflicted by the double burden of malnutrition, characterized by the coexistence of undernutrition and overweight/obesity (World Health Organization, 2017). Agricultural productivity is in fact one of the main drivers of a country nutrition transition: with a more productive agricultural system, food prices fall and consumers can afford more calories and proteins at lower prices. In this way, consumers in developing countries "embark on food consumption patterns reserved to industrialized countries" (Schmidhuber and Shetty, 2005: 14), favouring the uncontrolled rise of obesity and other NCDs.

In our analysis, we also account for two additional indicators. Fertility rates from World Bank data, which capture women empowerment, their labour participation, and the residual time they can spend in household and children care and are proved to have a non-negligible impact on household health and weight status. This negative relation (e.g. Blau, 1986; Beshara et al., 2010; Canning and Schultz, 2012; Horning et al., 2017) can have a twofold interpretation. On one side, lower fertility rates can improve living standards and health conditions, especially in developing countries, resulting in increased BMI (Canning and Schultz, 2012, Blau, 1986). On the other side, lower fertility rates may imply higher women's labour participation rates (e.g. Bloom et al., 2009), and higher risk of household weight gains (Milovanska-Farrington, 2020, Horning et al., 2017, Beshara et al., 2010, Pingali, 2007). The second, non-economic explanatory variable is the Polity2 index that measures the level of democracy on a scale from −10 (hereditary monarchy) to +10 (consolidated democracy. Democracies and economic freedom, though being able to reduce the burden of stunting and under-nourishment, may at the same time increase the share of overweight and obesity (e.g. Fumagalli et al., 2013; Lawson et al., 2016). On the other side, CC itself may be a driver a political instability (Dell et al., 2012).

The final sample, after having removed countries with missing information and Pacific Island Countries, which are disproportionately afflicted by NCDs (e.g. Hawley and McGarvey, 2015), consists of 134 countries (see Annex 6.1) observed from 1975 to 2014, for a total of 4,982 observations. Table 1 reports summary statistics of the variables described above and used in our empirical analysis.

## 2.2 A first look at the data

The dynamics of BMI are displayed in Figure 1, that plots the 1975 BMI vs. the 2014 BMI, picturing a relentless, positive increase for both children and adults, with different and heterogeneous growth rates. Figure 2 shows that the increase in obesity and weight gains are a global, rather than local, phenomenon, afflicting people of all ages and countries. In fact, the share of obese people has been remarkably increasing everywhere with African (Abarca-Gómez et al., 2017; Mchiza and Steyn, 2015; Bosu, 2015) and Asian countries (Yoon et al., 2006) recording the fastest growth rate, followed by Latin American countries (see Uauy et al., 2001; Rivera et al., 2014).

Hence, overweight is no longer plaguing advanced countries only, but is a major policy concern for developing countries, where the recent economic development and rapid urbanization have captured politicians' attention, at the expenses of obesity, which is now fast approaching the obesity prevalence of advanced economics (Abdullah, 2015).

Figure 3 reports the relation between average temperatures and residual BMI, as predicted from a fractional polynomial regression, a 'flexible parametric method for modelling relationships by using few parameters' (see Royston and Altman, 1997), using only country and year fixed effects. This procedure was implemented to obtain, a priori, the best fitting functional form for the effects of CC on BMI. This methodology has been previously implemented to estimate the relation between BMI and mortality (Wong et al., 2011). We obtained a U-shaped relation for both developed and developing countries (i.e. with a GDP per capita in the $4^{th}$ and first 3 quartiles of the 1975 GDP per capita distribution respectively), with the latter being already characterized by higher average annual temperatures (see Figure 4). In other words, BMI is decreasing and then increasing in average temperatures, so that the increase in temperatures induced by CC is going to be more detrimental to the BMI of hot countries. This pattern becomes more and more important as BMI levels at the extremes of the U-shaped relation are dangerously close to an overweight point of no return. Clearly, the above findings are mainly descriptive patterns in the above data that, though interesting and new, are not the results of a careful empirical analysis which is instead presented in the next Sections.

### 2.3 Empirical method

In the last years, there has been extensive use of panel data methods to estimate the relationship between inter-annual variation of weather and different economic, health and political outcomes, such as per-capita-GDP, mortality rate, wars and conflicts (see Dell et al. 2014; Carleton and Hsiang, 2016, for recent surveys).

The literature estimates variations of the following baseline specification:

$$y_{it} = \beta x_{it} + \gamma z_{it} + \alpha_i + \theta_t + \varepsilon_{it} \tag{1}$$

where $y_{it}$ it is the outcome variable of interest, namely BMI, observed in year $t$ of country $i$, $x_{it}$ is a vector of weather realization, $z_{it}$ is a vector of controls, $\alpha_i$ and $\theta_t$ are country and year fixed effects, respectively. Finally, $\varepsilon_{it}$ is an i.i.d. error term.

We use variations of equation (1) to study the extent to which interannual variations of weather (temperature and precipitations) have direct and/or mainly indirect effects on obesity. To reduce the risk of an "over-controlling problem", we initially do not introduce any control $z_{it}$ in our empirical specification. In fact, the introduction of explanatory factors, such as agricultural productivity, that in turn depends on climatic conditions, may "partially eliminate the explanatory power of climate, even if climate is the underlying fundamental cause" (Dell et al., 2014, pag. 743). More formally, equation (1) can be written as $y = f(\mathbf{X}, \mathbf{Z}(\mathbf{X}))$. Thus, estimating an equation that included both a vector of controls $\mathbf{Z}$ and weather variables $\mathbf{X}$ would not capture the true net effect of $\mathbf{X}$ on $y$. Dell et al. (2014) report the following example: "[…] consider the fact that poorer countries tend to be both hot and have low-quality institutions. If hot climates were to cause low-quality institutions, which in turn cause low income, then controlling for institutions in (1) can have the effect of partially eliminating the explanatory power of climate" (p. 743). However, later on, in order to shed light on the possible mechanisms driving our results, and to test whether climate variables have also a direct, independent, effects on BMI, we introduce also the vector of controls $z_{it}$ discussed earlier.

The critical issue of our identification is that equation (1) captures short-run or long-run effects of climate on BMI, depending on how weather variables enter the equation. More precisely, if $x$ enters non linearly, e.g. in a quadratic form, then equation (1) captures also long-run effects (see Mérel and Gammans, 2018, for a formal derivation). This consideration is important in our context, for though individual obesity can certainly display yearly variations, when measured at the country level, the (average) change in obesity tends to have a smoothed trend. To see why, and under which conditions, a non-linearity in the weather variable specification of equation (1) should also capture long-run effects, it is sufficient to understand the basic logic of a fixed-effect specification. Indeed, if the underlying Data Generating Process (DGP) implies a non-linearity of BMI to weather shocks, then the between weather variation in the units of observation, i.e. the mean country climate, enters the process of identification. This intuition has been firstly put forward by Schlenker (2006) and McIntosh and Schlenker (2006), and more recently formally extended by Mérel and Gammans (2018). More precisely, the critical reason is that the standard quadratic in weather specification with added fixed effects does not measure non-linearity within units, because by squaring the covariate (e.g. temperature) and then by demeaning it, a function of the mean of the covariate, i.e. climate, has been reintroduced into the fixed-effect model specification (see also the discussion in Hsiang, 2016, Deryugina and Hsiang, 2017, Carter et al., 2018). Lemoine (2018) further qualified under which specific conditions we can exploit weather variation to identify the (long-run) effect of climate. Hence, according to this logic, the results reported below should also be interpreted keeping in mind that, to a certain extent, we are capturing the long-run effect of climate on BMI, too. Mérel and Gammans (2018), using a Global dataset (167 countries and 50 years), calculated that the estimated coefficients of temperature in a standard quadratic specification capture long-run (short-run) temperature effects with weights of 98% (2%). Considering our sample of 134 country and 39 years, this means that our estimated temperature effects should be "biased" toward long-run effects.

## 3 Results: Estimating the overall effect of weather

In this Section, we discuss the overall impact of weather on BMI. We present results of six different regressions, including weather variables in their linear and quadratic forms. The baseline estimated equation is

$$y_{it} = \beta_1 t_{it} + \beta_2 t_{it}^2 + \beta_3 p_{it} + \beta_2 p_{it}^2 + \alpha_i + \theta_t + \varepsilon_{it} \qquad (2)$$

where $y_{it}$ is the BMI level of different groups in the population (children, boys, girls, adults, men and women), and $t_{it}$ and $p_{it}$ are the yearly average temperature and rainfalls; all other terms are as in equation (1).

Table 2 reports the results, showing that the overall (i.e. direct and indirect) effect of weather on BMI occurs through temperatures, rather than precipitations. In all the six regressions considered, the coefficient of the linear temperature is indeed negative and statistically significant, while the coefficient of temperature squared is always positive and significant, with the exception of the specification for men (Column 5). Hence, the signs of the linear and the quadratic temperature coefficients indicate a clear U-shaped relationship between temperatures and BMI that confirms the fit of Figure 3.

According to the results in Table 2, BMI first decreases and then rises with temperatures, with the turning point being a global minimum. The bottom of Table 2 reports the optimal temperature minimizing BMI and the values are obtained using the bootstrap procedure to account for the sampling uncertainty of our data. The patterns are clear and interesting.

In fact, there is a stark (6°C) difference in the BMI minimizing temperatures of children and adults, which are 17.5°C (95% CI 14–20°C) and 23.6°C respectively. Table 2 also proves the existence of a clear "gender difference" in the climate-BMI relation, with girls and women significantly more exposed to the obesity impact of temperature than boys and men in particular.

This analysis reveals that temperature is a significant driver of BMI increase. There are surely many other factors suggested by the literature that potentially contribute to this total effect, and they will be duly taken into account in the next Section.

## 4 Channels and the direct effect of weather on obesity

So far, we have uncovered a robust U-shaped relation between temperature and BMI, particularly robust for girls and women. In this Section, by adding several determinants of obesity suggested by the literature, we try to shed some light on the mechanisms at work, as well as on the extent to which weather has an independent direct effect on BMI. What we estimate is a very similar version of equation (2), that is

$$y_{it} = \beta_1 t_{it} + \beta_2 t_{it}^2 + \beta_3 p_{it} + \beta_2 p_{it}^2 + \gamma z_{it} + \alpha_i + \theta_t + \varepsilon_{it} \quad (3)$$

where $z_{it}$ is the vector of other transmission channels. Results are presented as follows: for each age and gender category, we estimate the climate-BMI relation introducing one alternative determinant at a time. As stressed earlier, the transmission channels considered are GDP per capita (linearly and squared), fertility rates, agricultural productivity, trade, and institutional quality. The detailed results of this analysis are reported in Annex 6.2. Here, for the sake of convenience, we display for each group considered the joint statistical significance of the two temperature coefficients (see Figure 5) as resulting from the specification of Table 2 and from the regression specifications with one and all the transmission channels. That is, we performed a joint F-test on the linear and quadratic temperature coefficients of temperature, i.e. $\beta_1$ and $\beta_2$ in both equations (2) and (3). According to the null hypothesis, the two terms are jointly equal to zero. When the null is rejected, the two terms are jointly different from zero.

Figure 5 clearly shows that the temperature coefficients, even when controlling for many other determinants of BMI, retain their significant level, a result which is particularly robust for girls and women, for whom the joint statistical significance always exceeds 95% and 99% respectively. For children and adults, the joint statistical significance is always greater than 95%, with the exception of the specification for adults with fertility, where the joint significance is 94%. Last but not least, for boys and men the joint statistical significance exceeds 95% with either GDP per capita and fertility. In Figure 5, the statistical significance for boys was truncated at 70%. Hence the actual level for the fertility specification and the specification with all controls is below 70%.

Hence, Figure 5 reveals that we also have a direct and independent effect of CC on BMI, at least when girls and women are considered, and less for the other groups.

Table 3 reports the regression results when all the transmission channels are considered simultaneously, revealing that the U-shaped effects of temperatures on the BMI of children, girls, and women survive the contemporaneous introduction of other explanatory mechanisms. The U-shaped relation for children and girls is proved to be robust to the introduction of extreme weather events, but not for women, for whom the quadratic term is no longer statistically significant. Results are omitted here for the sake of convenience.

Table 3 also confirms that GDP per capita, fertility and agricultural productivity are important predictors of obesity for almost all the age and gender categories. Indeed, the hump-shaped effects of GDP per capita on the BMI of children, boys, and men recalls the Kuznets curve of obesity discussed by Abdullah (2015) and also observed by Ameye and Swinnen (2019). In other words, the double burden of malnutrition has increased with GDP per capita in developing countries. Interestingly enough, the BMI levels of girls and women are not influenced by the economic development of a country, in a vein similar to Wells et al. (2012), where women's obesity is explained more by indicators of economic and social inequality than by GDP per capita. The effects of fertility are unquestionably negative and statistically significant in all the empirical specifications considered, but that for men, in line with the evidence discussed in Section 2.1. Regardless of how one can interpret reduced fertility, that, as stressed earlier, may either imply increased household resources that could be devoted to one child or higher women labour participation, its impact on BMI cannot be neglected. Agricultural productivity is a strong obesity driver also in our setting: in fact, Table 3 clearly points out that agricultural productivity has a strong and positive effect on obesity of people of all ages and gender, the only exception being the group of girls. Still, when introduced alone, without the other transmission channels, agricultural productivity is positive and significant for girls, too, as reported in Table A.7 in Annex 6.2. Our results are thus in line with the conclusions of Schmidhuber and Shetty (2005).

In our setting, trade openness and institutional quality are only limited drivers of obesity. Differently from previous research on the topic (e.g. An et al., 2019, Oberlander et al., 2017, Goryakin et al., 2015, and De Vogli et al., 2013), the trade coefficients reported in Table 3 are negative for boys, adults, and women, but statistically significant only at the 10% level. As for institutional quality, in spite of the negative relation observed by the literature discussed earlier, we fail to identify a direct effect on obesity.

Summarizing, our analysis proves that the effects of temperature variation on BMI are robust to the inclusion of other transmission channels highlighted by the literature. In fact, for children, girls, and women, the effects of temperatures are still characterized by a U-shaped relation, whereas men's obesity linearly decreases as temperatures rise. Moreover, our results indicate that economic development, fertility rates and agricultural productivity are important transmission channels strongly contributing to BMI and obesity. However, and importantly, we also show that temperature has an independent direct effect on BMI, that still results non-linear for children, girls and women, but is negative for adults.

## 5 Discussion and conclusions

This study develops an exploratory analysis to establish the existence of a climate-obesity nexus. As of today, changes in dietary habits and the reduction in physical activity are considered two main explanations for BMI increases, but recent studies have pointed out that there could be other contributors unbalancing the equilibrium between energy expenditure and intake, such as ambient or environmental conditions where people live (Keith et al., 2006; Johnson et al., 2011). However, the studies investigating this relationship are limited in scope, focusing on ambient (indoor) temperature and reporting contrasting results. For instance, BMI, waist circumference and waist-to-height ratio in Tibetans were lower in subjects living at higher altitudes with respect to those living at lower altitudes, probably as a consequence of the catabolic effects induced by low temperatures and low oxygen at higher altitudes (Sherpa et al., 2010). Conversely, a cross-sectional population-based survey performed in Spain by Valdes et al. (2014) showed a positive relationship between ambient temperature and obesity, while a nationwide population-based survey performed in Korea pointed out the maximum prevalence for obesity in counties showing average temperatures close to 18°C (Yang et al., 2015). The discrepancy in the relationships between ambient temperature and obesity found in previous studies might be due to differences in mean temperature ranges, altitudes of areas, ethnic groups, as well as to heterogeneous adjustment to confounding variables (Yang et al., 2015).

In the present study, we first investigated the relationship between temperature and obesity, in terms of BMI, in children and adults from 134 Countries over 39 years. Such relationship was described by consistent U-shaped curves for almost all the age and gender groups considered, whereby BMI increased mostly at warm temperatures. Our results display a robust, direct and independent effect of temperature mainly for children, girls and women, while the direct effect of temperature is largely mediated by the level of development and agricultural productivity when boys and men are concerned. Such gender-related discrepancy confirms the heterogenous effects of weather conditions already discussed by Cawley (2015), Carleton et al. (2018), and Dell et al., (2014). In our framework, this climate-obesity nexus, with age and gender specific effects, might depend on differences in thermoregulation due to different body characteristics and endocrinal physiology occurring between children and adults, and between males and females (Tikuisis et al., 2000; Kaciuba-Uscilko and Grucza, 2001; Kingma et al., 2012). For instance, females sweat at higher heat loads and have lower metabolic rates (up to −35%) than males (e.g. Byrne et al., 2005; Ichinose-Kuwahara et al., 2010), thus explaining the different gender-related regulation of energy expenditure to regulate body temperature.

Interestingly, the increase in BMI was noted at temperatures near and over the upper limit of the thermoneutral zone (TNZ) (see Table 2), commonly defined as the range of ambient temperatures whereby the body can maintain its core temperature solely through regulating dry heat loss, without the activation of metabolic processes leading to heat production or heat loss (Kingma et al., 2012, 2014). Limited or no energy is required to stabilize the core temperature of the body within the TNZ, while changes in ambient temperature can contribute to distance the organisms from their TNZ. For instance, when humans spend their time in an environment where the temperature is below the TNZ, basic physiological and metabolic processes are activated to satisfy the increased thermogenic demand, resulting in heat production and the preservation of core body temperature (Cannon and Nedergaard, 2004). In contrast, when the ambient temperature rises above the upper limit of the TNZ, physiologic and metabolic processes are activated to amplify heat dissipation (Davis, 1964).

The TNZ has been suggested to range between 28 and 32 °C (Hardy et al., 1938), but Hill and co-authors (2013) have reported a lower critical temperature (LCT) of 26 – 27 °C for naked humans. According to a biophysical thermal study, the steady state human TNZ might range between 26 °C and 33 °C (Kingma et al., 2014), even though in clothed humans this range could be between 15 and 24.5 °C due to the insulation provided by clothes (Kingma et al., 2014). Despite these findings, recent dynamic experiments have demonstrated that the LCT of the TNZ was lower (ca. 23 °C) compared to previous studies, while the upper critical temperature could not be determined because of negligible or even completely absent changes in metabolic rate occurred after experiencing warming conditions (up to 37.5 ± 0.6 °C or 41.6 ± 1.0 °C for six individuals only; Pallubinsky et al., 2019). Moreover, indications exist that the TNZ might be shifted by acclimation to warm or cold ambient conditions (Pallubinsky et al., 2017; van der Lans et al., 2013) and it is likely to be accustomed to the specific thermal habitat of an individual (Brown et al., 2004; Kingma et al., 2012).

Considering the uncertainty in defining the position and the shape of the human TNZ, as well as the positive relationship between environmental temperature and BMI we noted at temperatures over 23 °C, we might speculate that humans reduce their energy expenditure (and consequently experience a weight gain) because they face a temperature within the TNZ and/or are acclimated to warmer temperatures. Evidences of decreased energy balance beyond either side of the TNZ at which increased metabolic expenditures are required to cope with either very hot or very cold temperatures were observed (e.g. McAllister et al., 2009). According to this hypothesis, several studies demonstrated that energy expenditure in humans is negatively associated with thermal environment over a range of ambient temperatures from 15°C to 28°C (Johnson et al., 2011, and references therein). Accordingly, a previous population-based study performed on an Italian cohort, investigating the relationships between obesity and diverse contributors, including sleep restriction, increased house temperature, television watching, consumption of restaurant meals, use of air conditioning and use of antidepressant or antipsychotic drugs estimated a two-fold increase in risk for obesity incidence in subjects living at an indoor temperature greater than 20°C (Bo et al., 2011). The authors suggested that within the TNZ no energy expenditure is necessary to maintain a thermic homeostasis, resulting in an increased BMI. Moreover, recent studies also suggested that global warming results in water shortage, which increases fat mass as a means to provide metabolic water, and that the increase of environmental temperature affects birth weight, which is associated with BMI in late adolescence (van Hanswijck de Jonge et al., 2002; Johnson et al., 2016). Alternatively, the positive relationship occurring between BMI and cold or warm temperatures might be due to the reduction in physical activity. When temperature is too cold or too hot to go outdoor, where most of adults' physical activity is performed (Dannenberg et al., 1989), a reduction in physical activity was observed, resulting in more sedentary lifestyles (Obradovich and Fowler, 2017) and consequently in weight gain.

In the present study, we also test for the existence of direct effects of temperatures on BMI, that is, once other relevant transmission channels reported by previous works have been included. We observe that the effects of temperature on BMI do survive the inclusion of these additional factors. On top of that, we also observe that fertility and agricultural productivity might respectively alleviate or increase the burden of weight gains and obesity.

The results of this exploratory assessment should encourage further research on this topic. The CC-obesity nexus that emerges from our analysis suggests that obesity-oriented food security policies should be implemented especially in those countries that are threatened the most by CC and rising temperatures. Indeed, overweight and obesity are as equally important as undernourishment, especially in a long-term perspective.

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# Appendices

## A1. Countries included in the sample

The Table below reports the countries included in the sample.

Table A1: List of Countries

| Continent | Countries |
|---|---|
| OECD | Australia, Austria, Belgium, Canada, Chile, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Israel, Italy, Japan, Latvia, Lithuania, Luxembourg, Mexico, Netherlands, New Zealand, Norway, Poland, Portugal, Slovakia, Slovenia, South Korea, Spain, Sweden, Switzerland, Turkey, United Kingdom, USA |
| Latin America | Argentina, Bolivia, Brazil, Colombia, Costa Rica, Dominican Republic, Ecuador, El Salvador, Guatemala, Haiti, Honduras, Jamaica, Nicaragua, Panama, Paraguay, Peru, Suriname, Trinidad and Tobago, Uruguay, Venezuela |
| Africa | Algeria, Angola, Benin, Botswana, Burkina Faso, Burundi, Cameroon, Central African Republic, Chad, Congo, Egypt, Equatorial Guinea, Ethiopia, Gabon, Gambia, Ghana, Guinea Kenya, Lesotho, Liberia, Madagascar, Malawi, Mali, Mauritania, Mauritius, Morocco, Mozambique, Namibia, Niger, Nigeria, Rwanda, Senegal, Sierra Leone, South Africa, Sudan, Swaziland, Tanzania, Togo, Tunisia, Uganda, Zambia, Zimbabwe |
| Asia | Armenia, Azerbaijan, Bahrain, Bangladesh, Bhutan, Cambodia, China, Djibouti, Georgia, India, Indonesia, Iran, Iraq, Jordan, Kazakhstan, Kuwait, Kyrgyzstan, Lao PDR, Lebanon, Malaysia, Mongolia, Myanmar, Nepal, Oman, Pakistan, Philippines, Qatar, Saudi Arabia, Singapore, Sri Lanka, Syrian Arab Republic, Tajikistan, Thailand, Turkmenistan, Uzbekistan, Viet Nam, Yemen |

## A2. Alternative transmission channels: detailed regression results

Table A2: Robustness results – children

| | **(1)** | **(2)** | **(3)** | **(4)** | **(5)** |
|---|---|---|---|---|---|
| Temperature | -0.107*** | -0.060** | -0.070*** | -0.086*** | -0.098*** |
| | (0.026) | (0.025) | (0.023) | (0.026) | (0.026) |
| Temperature$^2$ | 0.003*** | 0.002** | 0.002** | 0.002*** | 0.003*** |
| | (0.001) | (0.001) | (0.001) | (0.001) | (0.001) |
| Precipitations | -0.001 | -0.001 | -0.002 | -0.001 | -0.002 |
| | (0.001) | (0.001) | (0.001) | (0.001) | (0.001) |
| Precipitations$^2$ | 0.000 | 0.000 | 0.000* | 0.000* | 0.000* |
| | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) |
| GDP per capita | 97.815** | | | | |
| | (48.723) | | | | |
| GDP per capita$^2$ | -48.858** | | | | |
| | (24.349) | | | | |
| Fertility | | -0.098*** | | | |
| | | (0.025) | | | |
| Agricultural productivity | | | 0.198*** | | |
| | | | (0.062) | | |
| Trade openness | | | | -0.652** | |
| | | | | (0.268) | |
| Polity 2 | | | | | -0.001 |
| | | | | | (0.003) |
| Country FE | Yes | Yes | Yes | Yes | Yes |
| Year FE | Yes | Yes | Yes | Yes | Yes |
| | | | | | |
| $R^2$ | 0.891 | 0.897 | 0.893 | 0.89 | 0.889 |
| N | 4982 | 4982 | 4982 | 4982 | 4982 |

Statistical significance: * significant at 10%; ** significant at 5%; *** significant at 1%. Standard clustered errors are reported in parenthesis. GDP per capita, squared GDP per capita and agricultural productivity in log form. Trade openness standardized in the interval (0,1).

Table A3: Robustness results – boys

| | (1) | (2) | (3) | (4) | (5) |
|---|---|---|---|---|---|
| Temperature | -0.086*** | -0.031 | -0.039 | -0.058** | -0.073** |
| | (0.029) | (0.023) | (0.024) | (0.028) | (0.029) |
| Temperature$^2$ | 0.002*** | 0.001 | 0.001 | 0.002* | 0.002** |
| | (0.001) | (0.001) | (0.001) | (0.001) | (0.001) |
| Precipitations | -0.001 | -0.001 | -0.002 | -0.002 | -0.002* |
| | (0.001) | (0.001) | (0.001) | (0.001) | (0.001) |
| Precipitations$^2$ | 0.000* | 0.000* | 0.000* | 0.000** | 0.000** |
| | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) |
| GDP per capita | 141.342*** | | | | |
| | (52.497) | | | | |
| GDP per capita$^2$ | -70.599*** | | | | |
| | (26.236) | | | | |
| Fertility | | -0.109*** | | | |
| | | (0.023) | | | |
| Agricultural productivity | | | 0.239*** | | |
| | | | (0.064) | | |
| Trade openness | | | | -0.822*** | |
| | | | | (0.298) | |
| Polity 2 | | | | | -0.002 |
| | | | | | (0.003) |
| Country FE | Yes | Yes | Yes | Yes | Yes |
| Year FE | Yes | Yes | Yes | Yes | Yes |
| | | | | | |
| $R^2$ | 0.907 | 0.913 | 0.909 | 0.906 | 0.904 |
| N | 4982 | 4982 | 4982 | 4982 | 4982 |

Statistical significance: * significant at 10%; ** significant at 5%; *** significant at 1%. Standard clustered errors are reported in parenthesis. GDP per capita, squared GDP per capita and agricultural productivity in log form. Trade openness standardized in the interval (0,1).

Table A4: Robustness results – girls

| | (1) | (2) | (3) | (4) | (5) |
|---|---|---|---|---|---|
| Temperature | -0.128*** | -0.090*** | -0.101*** | -0.114*** | -0.122*** |
| | (0.032) | (0.034) | (0.03) | (0.033) | (0.032) |
| Temperature$^2$ | 0.004*** | 0.003** | 0.003*** | 0.003*** | 0.004*** |
| | (0.001) | (0.001) | (0.001) | (0.001) | (0.001) |
| Precipitations | -0.001 | -0.001 | -0.001 | -0.001 | -0.001 |
| | (0.001) | (0.001) | (0.001) | (0.001) | (0.001) |
| Precipitations$^2$ | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) |
| GDP per capita | 54.288 | | | | |
| | (52.192) | | | | |
| GDP per capita$^2$ | -27.118 | | | | |
| | (26.081) | | | | |
| Fertility | | -0.087** | | | |
| | | (0.034) | | | |
| Agricultural productivity | | | 0.157** | | |
| | | | (0.075) | | |
| Trade openness | | | | -0.482 | |
| | | | | (0.364) | |
| Polity 2 | | | | | 0 |
| | | | | | (0.004) |
| Country FE | Yes | Yes | Yes | Yes | Yes |
| Year FE | Yes | Yes | Yes | Yes | Yes |
| | | | | | |
| $R^2$ | 0.805 | 0.811 | 0.807 | 0.805 | 0.805 |
| N | 4982 | 4982 | 4982 | 4982 | 4982 |

Statistical significance: * significant at 10%; ** significant at 5%; *** significant at 1%. Standard clustered errors are reported in parenthesis. GDP per capita, squared GDP per capita and agricultural productivity in log form. Trade openness standardized in the interval (0,1).

Table A5: Robustness results – adults

| | **(1)** | **(2)** | **(3)** | **(4)** | **(5)** |
|---|---|---|---|---|---|
| Temperature | -0.258*** | -0.214*** | -0.199*** | -0.248*** | -0.267*** |
| | (0.064) | (0.055) | (0.059) | (0.059) | (0.063) |
| Temperature$^2$ | 0.005*** | 0.004** | 0.004** | 0.005*** | 0.006*** |
| | (0.002) | (0.002) | (0.002) | (0.002) | (0.002) |
| Precipitations | -0.001 | 0 | -0.001 | -0.001 | -0.001 |
| | (0.001) | (0.001) | (0.001) | (0.001) | (0.001) |
| Precipitations$^2$ | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) |
| GDP per capita | -200.92 | | | | |
| | (173.614) | | | | |
| GDP per capita$^2$ | 100.399 | | | | |
| | (86.77) | | | | |
| Fertility | | -0.157*** | | | |
| | | (0.043) | | | |
| Agricultural productivity | | | 0.551*** | | |
| | | | (0.13) | | |
| Trade openness | | | | -1.447** | |
| | | | | (0.558) | |
| Polity 2 | | | | | 0.007 |
| | | | | | (0.006) |
| Country FE | Yes | Yes | Yes | Yes | Yes |
| Year FE | Yes | Yes | Yes | Yes | Yes |
| | | | | | |
| $R^2$ | 0.913 | 0.918 | 0.92 | 0.914 | 0.913 |
| N | 4982 | 4982 | 4982 | 4982 | 4982 |
| Statistical significance: * significant at 10%; ** significant at 5%; *** significant at 1%. Standard clustered errors are reported in parenthesis. GDP per capita, squared GDP per capita and agricultural productivity in log form. Trade openness standardized in the interval (0,1). | | | | | |

Table A6: Robustness results – men

| | **(1)** | **(2)** | **(3)** | **(4)** | **(5)** |
|---|---|---|---|---|---|
| Temperature | -0.092** | -0.064* | -0.051 | -0.076** | -0.089** |
| | (0.039) | (0.035) | (0.037) | (0.036) | (0.038) |
| Temperature$^2$ | 0.002 | 0.001 | 0.001 | 0.001 | 0.002 |
| | (0.001) | (0.001) | (0.001) | (0.001) | (0.001) |
| Precipitations | -0.001 | 0 | -0.001 | -0.001 | -0.001 |
| | (0.001) | (0.001) | (0.001) | (0.001) | (0.001) |
| Precipitations$^2$ | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) |
| GDP per capita | 71.141 | | | | |
| | (60.557) | | | | |
| GDP per capita$^2$ | -35.548 | | | | |
| | (30.255) | | | | |
| Fertility | | -0.062** | | | |
| | | (0.028) | | | |
| Agricultural productivity | | | 0.266*** | | |
| | | | (0.077) | | |
| Trade openness | | | | -0.655** | |
| | | | | (0.3) | |
| Polity 2 | | | | | -0.002 |
| | | | | | (0.004) |
| Country FE | Yes | Yes | Yes | Yes | Yes |
| Year FE | Yes | Yes | Yes | Yes | Yes |
| | | | | | |
| $R^2$ | 0.955 | 0.956 | 0.957 | 0.955 | 0.955 |
| N | 4982 | 4982 | 4982 | 4982 | 4982 |

Statistical significance: * significant at 10%; ** significant at 5%; *** significant at 1%. Standard clustered errors are reported in parenthesis. GDP per capita, squared GDP per capita and agricultural productivity in log form. Trade openness standardized in the interval (0,1).

Table A7: Robustness results – women

| | (1) | (2) | (3) | (4) | (5) |
|---|---|---|---|---|---|
| Temperature | -0.425*** | -0.364*** | -0.346*** | -0.420*** | -0.446*** |
| | (0.098) | (0.086) | (0.091) | (0.092) | (0.098) |
| Temperature$^2$ | 0.009*** | 0.007** | 0.007** | 0.009*** | 0.010*** |
| | (0.003) | (0.003) | (0.003) | (0.003) | (0.003) |
| Precipitations | -0.001 | 0 | -0.001 | -0.001 | -0.001 |
| | (0.002) | (0.002) | (0.002) | (0.002) | (0.002) |
| Precipitations$^2$ | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) |
| GDP per capita | -472.982 | | | | |
| | (302.344) | | | | |
| GDP per capita$^2$ | 236.346 | | | | |
| | (151.115) | | | | |
| Fertility | | -0.252*** | | | |
| | | (0.071) | | | |
| Agricultural productivity | | | 0.835*** | | |
| | | | (0.201) | | |
| Trade openness | | | | -2.239** | |
| | | | | (0.891) | |
| Polity 2 | | | | | 0.017* |
| | | | | | (0.009) |
| Country FE | Yes | Yes | Yes | Yes | Yes |
| Year FE | Yes | Yes | Yes | Yes | Yes |
| | | | | | |
| $R^2$ | 0.84 | 0.847 | 0.851 | 0.838 | 0.837 |
| N | 4982 | 4982 | 4982 | 4982 | 4982 |

Statistical significance: * significant at 10%; ** significant at 5%; *** significant at 1%. Standard clustered errors are reported in parenthesis. GDP per capita, squared GDP per capita and agricultural productivity in log form. Trade openness standardized in the interval (0,1).

## Figure captions

Figure 1: Change in children's and adults' BMI (1975 vs. 2014)

Figure 2: Average percentage increase in share of obese people 1975-2014

Figure 3: BMI and temperatures for children and adults: all countries vs. developing countries

Figure 4: Temperature distribution in developed and developing countries

Figure 5: Joint statistical significance of temperature coefficients on BMI when including also other transmission channels

# Tables

Table 1: Summary statistics

| | **Mean** | **St. dev.** | **Min** | **Max** |
|---|---|---|---|---|
| BMI children | 18.23973 | 1.243188 | 15.18411 | 21.80638 |
| BMI boys | 17.97622 | 1.407212 | 14.75939 | 22.21194 |
| BMI girls | 18.50324 | 1.143365 | 15.60884 | 22.07404 |
| BMI adults | 23.74959 | 2.407474 | 17.38449 | 29.77055 |
| BMI men | 23.43744 | 2.426913 | 18.0575 | 28.97508 |
| BMI women | 24.06173 | 2.553143 | 16.39959 | 31.35141 |
| Temperature (° C) | 19.25147 | 7.926185 | -7.93095 | 29.74765 |
| Precipitations (mm/year) | 91.34386 | 63.94889 | 1.141713 | 316.2797 |
| GDP per capita | 11371.6 | 14602.92 | 142.3924 | 159825.7 |
| Trade openness | 0.079453 | 0.075845 | 8.03E-18 | 1 |
| Agricultural productivity (Int $/ha) | 1015.742 | 3981.637 | 4.70604 | 93381.51 |
| Fertility | 3.85729 | 1.941248 | 1.076 | 8.713 |
| Polity 2 | 1.665998 | 7.313968 | -10 | 10 |

Table 2: The direct effect

| | **Children** | **Boys** | **Girls** | **Adults** | **Men** | **Women** |
|---|---|---|---|---|---|---|
| Temperature | -0.097*** | -0.071** | -0.122*** | -0.273*** | -0.087** | -0.458*** |
| | (0.026) | (0.028) | (0.033) | (0.063) | (0.038) | (0.099) |
| Temperature$^2$ | 0.003*** | 0.002** | 0.003*** | 0.006*** | 0.002 | 0.010*** |
| | (0.001) | (0.001) | (0.001) | (0.002) | (0.001) | (0.003) |
| Precipitations | -0.002 | -0.002* | -0.001 | -0.001 | -0.001 | -0.001 |
| | (0.001) | (0.001) | (0.001) | (0.001) | (0.001) | (0.002) |
| Precipitations$^2$ | 0.000* | 0.000** | 0.000 | 0.000 | 0.000 | 0.000 |
| | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) |
| Country FE | Yes | Yes | Yes | Yes | Yes | Yes |
| Year FE | Yes | Yes | Yes | Yes | Yes | Yes |
| | | | | | | |
| Minimum BMI growth temperature (° C) | 17.48*** | 17.54*** | 17.44*** | 23.77*** | 24.88*** | 23.57*** |
| Minimum temperature 95% quantile range (° C) | [14.92-20.04] | [14-21.08] | [14.80-20.08] | [20.99-26.55] | [17.10-32.65] | [21.15-25.99] |
| | | | | | | |
| Marginal effect of a 1° C uniform increase in average temperatures | | | | | | |
| Whole sample | 0.90% | 0.60% | 1.20% | **-5%** | **-1.90%** | **-8%** |
| Developing countries | 3.90% | 2.80% | 4.90% | 0.80% | -0.10% | 1.80% |
| | | | | | | |
| $R^2$ | 0.889 | 0.904 | 0.805 | 0.912 | 0.955 | 0.835 |
| N | 4982 | 4982 | 4982 | 4982 | 4982 | 4982 |

Statistical significance: * significant at 10%; ** significant at 5%; *** significant at 1%. Standard clustered errors are reported in parenthesis. The turning point is obtained from the following ratio: $-\beta_1/(2\beta_2)$. To account for sampling heterogeneity, the minimum BMI growth temperature (and their 95% Confidence Intervals) are obtained through a bootstrapping procedure on 500 replications. The sample marginal effect of a 1° C uniform increase in average temperatures is defined as $\beta_1 + 2\ \beta_2 * avg\_temp$, where *avg_temp* is the sample average temperature, and it has been computed trough a bootstrapping procedure on 500 replications. Marginal effects in bold are statistically significant at 1 or 5%; marginal effects in italic are statistically significant at 10%.

Table 3: Joint effects

| | **Children** | **Boys** | **Girls** | **Adults** | **Men** | **Women** |
|---|---|---|---|---|---|---|
| Temperature | -0.054** | -0.024 | -0.084*** | -0.149*** | -0.04 | -0.258*** |
| | (0.021) | (0.02) | (0.029) | (0.053) | (0.035) | (0.081) |
| Temperature$^2$ | 0.002** | 0.001 | 0.002** | 0.003 | 0 | 0.005* |
| | (0.001) | (0.001) | (0.001) | (0.001) | (0.001) | (0.003) |
| Precipitations | -0.001 | -0.001 | -0.001 | -0.001 | 0 | -0.001 |
| | (0.001) | (0.001) | (0.001) | (0.001) | (0.001) | (0.002) |
| Precipitations$^2$ | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) |
| GDP per capita | 164.205** | 217.814*** | 110.597 | -67.635 | 130.863*** | -266.134 |
| | (71.922) | (81.854) | (67.065) | (120.361) | (49.575) | (219.176) |
| GDP per capita$^2$ | -82.043** | -108.824*** | -55.263 | 33.781 | -65.401*** | 132.962 |
| | (35.948) | (40.912) | (33.518) | (60.152) | (24.766) | (109.544) |
| Fertility | -0.090*** | -0.098*** | -0.081** | -0.094** | -0.041 | -0.148** |
| | (0.026) | (0.023) | (0.038) | (0.043) | (0.029) | (0.067) |
| Agricultural productivity | 0.144** | 0.183*** | 0.104 | 0.462*** | 0.248*** | 0.675*** |
| | (0.063) | (0.056) | (0.088) | (0.135) | (0.082) | (0.202) |
| Trade openness | -0.278 | -0.417* | -0.139 | -0.924* | -0.45 | -1.398* |
| | (0.258) | (0.237) | (0.405) | (0.5) | (0.296) | (0.771) |
| Polity 2 | -0.002 | -0.003 | -0.001 | 0.005 | -0.003 | 0.012 |
| | (0.003) | (0.002) | (0.004) | (0.006) | (0.004) | (0.008) |
| Country FE | Yes | Yes | Yes | Yes | Yes | Yes |
| Year FE | Yes | Yes | Yes | Yes | Yes | Yes |
| $R^2$ | 0.902 | 0.921 | 0.814 | 0.925 | 0.958 | 0.862 |
| N | 4982 | 4982 | 4982 | 4982 | 4982 | 4982 |

Statistical significance: * significant at 10%; ** significant at 5%; *** significant at 1%. Standard clustered errors are reported in parenthesis. GDP per capita, squared GDP per capita and agricultural productivity in log form. Trade openness standardized in the interval (0,1).

# Figures

Figure 1: Change in children's and adults' BMI (1975 vs. 2014)

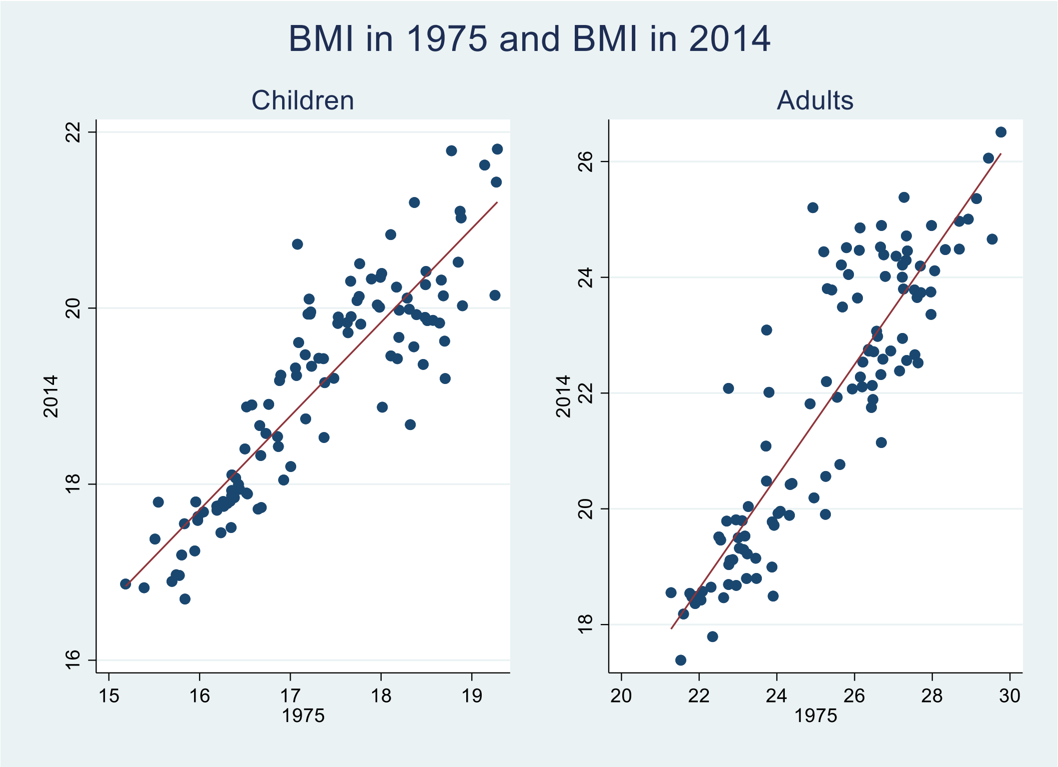


Figure 2: Average percentage increase in share of obese people 1975-2014

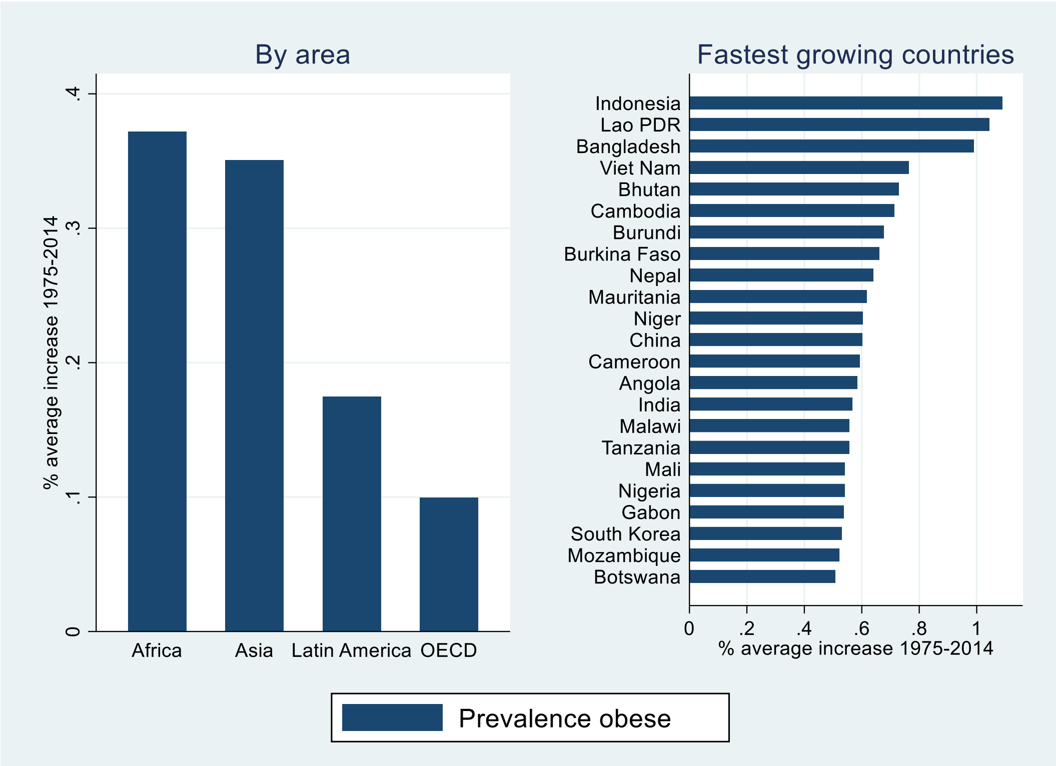


Figure 3: BMI and temperatures for children and adults: all countries vs. developing countries

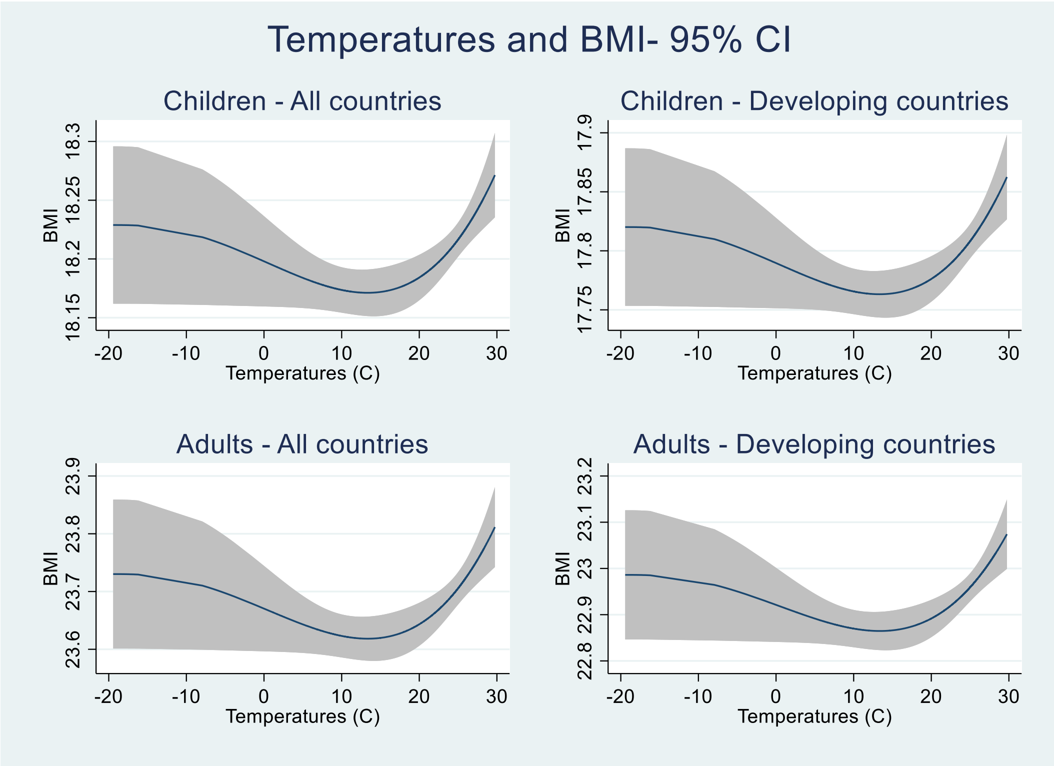


Figure 4: Temperature distribution in developed and developing countries

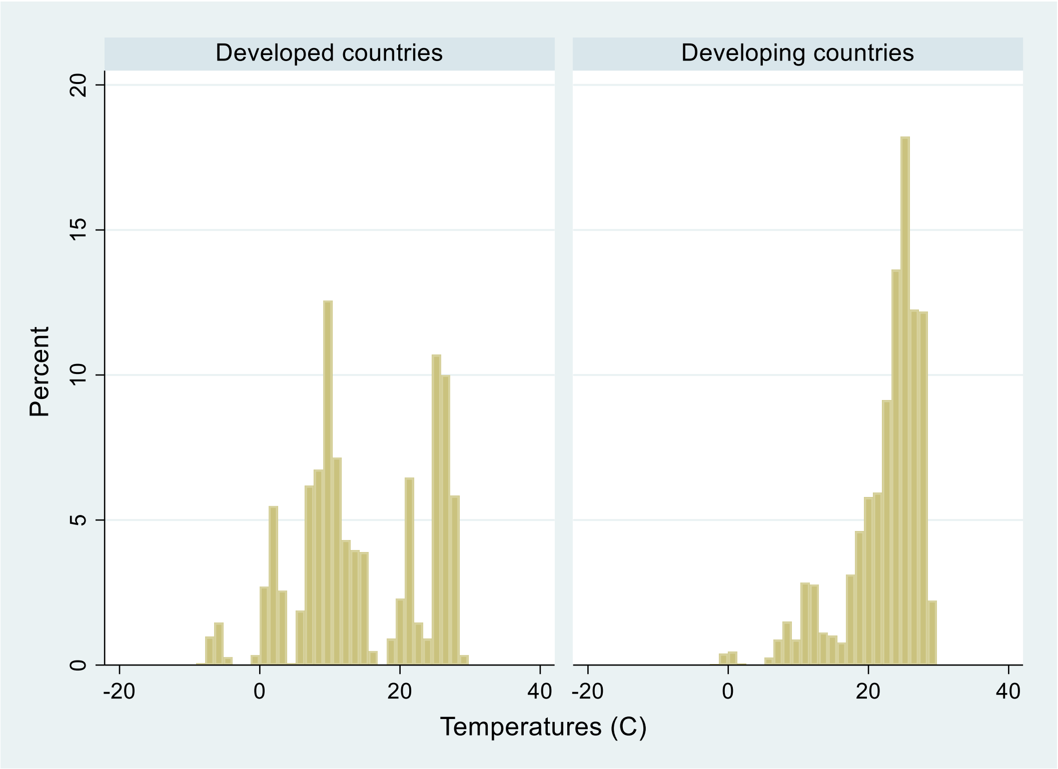
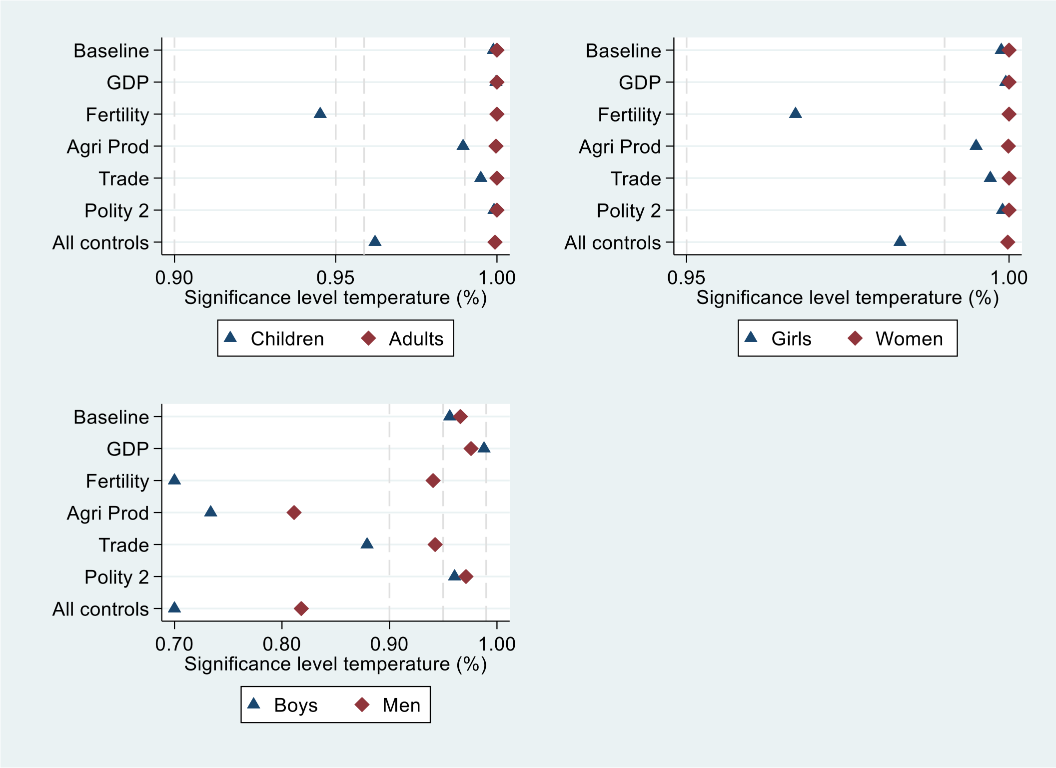


Figure 5: Joint statistical significance of temperature coefficients on BMI when including also other transmission channels



**Declaration of interests**

☒ The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

☐The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: