



The 'Heart Kuznets Curve'? Understanding the relations between economic development and cardiac conditions



Hitoshi Nagano^a, Jose A. Puppim de Oliveira^{b,f,*}, Allan Kardec Barros^c, Altair da Silva Costa Junior^{d,e}

^a Fundação Getulio Vargas (FGV/EAESP), Brazil

^b Fundação Getulio Vargas (FGV/EAESP and FGV/EBAPE), Brazil

^c Universidade Federal do Maranhão (UFMA), Brazil

^d SURGP&D – Company for Research and Development in Medicine/Surgery, Brazil

^e Paulista School of Medicine/Sao Paulo University Hospital – Federal University of Sao Paulo, Brazil

^f Institute for Global Public Policy and School of International Relations and Public Affairs (SIRPA), Fudan University, China

ARTICLE INFO

Article history:

Accepted 19 March 2020

Available online 30 April 2020

Keywords:

Kuznets Curve

Economic development

Health policy

Heart risk factors, blood pressure

ABSTRACT

As countries turn wealthier, some health indicators, such as child mortality, seem to have well-defined trends. However, others, including cardiovascular conditions, do not follow clear linear patterns of change with economic development. Abnormal blood pressure is a serious health risk factor with consequences for population growth and longevity as well as public and private expenditure in health care and labor productivity. This also increases the risk of the population in certain pandemics, such as COVID-19. To determine the correlation of income and blood pressure, we analyzed time-series for the mean systolic blood pressure (SBP) of men's population (mmHg) and nominal Gross Domestic Product per capita (GDPPC) for 136 countries from 1980 to 2008 using regression and statistical analysis by Pearson's correlation (r). Our study finds a trend similar to an inverted-U shaped curve, or a 'Heart Kuznets Curve'. There is a positive correlation (increase GDPPC, increase SBP) in low-income countries, and a negative correlation in high-income countries (increase GDPPC, decrease SBP). As country income rises people tend to change their diets and habits and have better access to health services and education, which affects blood pressure. However, the latter two may not offset the rise in blood pressure until countries reach a certain income. Investing early in health education and preventive health care could avoid the sharp increase in blood pressure as countries develop, and therefore, avoiding the 'Heart Kuznets Curve' and its economic and human impacts.

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1. Introduction

The relation between economic development and health outcomes puzzles both economists and public health scholars (Clark, 2011). In recent decades, most countries advanced in nominal Gross Domestic Product per capita (GDPPC), but not in all health indicators (Braveman et al., 2005; Banerjee, 2013). Some health indicators, such as child mortality or malnutrition, seem to have a well-defined declining trend as countries and individuals turn wealthier (Burkitt, 1973; Fedorov & Sahn, 2005; Fogel, 2004; Chen, Lei, & Zhou, 2017). However, others, such as cardiovascular

and various non-communicable diseases, do not follow clear patterns of change with economic development.

Socioeconomic factors, such as economic resources (e.g. income), inequality, social relations, education and occupation, are commonly used to explain health outcomes and investments (Aly & Grabowski, 1990; Braveman et al., 2005; Clark, 2011; Jürges, Kruk, & Reinhold, 2013; Woolf et al., 2015; Brunello, Fort, Schneeweis, & Winter-Ebmer, 2016; Lundborg, Nilsson, & Rooth, 2016). For example, higher education is a strong indicator for normal blood pressure (Colhoun, Hemingway, & Poulter, 1998; Conen, Glynn, Ridker, Buring, & Albert, 2009; Danaei et al., 2013). Certain studies mention that income and education are inversely associated with cardiovascular diseases, and low socio-economic condition is related to a higher prevalence of cardiovascular risk factors, such as high blood pressure (Colhoun et al., 1998; Braveman et al., 2005). There is also a correlation between income

* Corresponding author at: Management School of São Paulo (EAESP), Department of Public Management (GEP), Rua Itapeva, 474 – 7º andar, São Paulo, SP 01332-000, Brazil.

E-mail addresses: hitoshi.nagano@fgv.br (H. Nagano), jose.puppim@fgv.br (J.A. Puppim de Oliveira), allan.kardec@ufma.br (A.K. Barros), altair.torax@gmail.com (A.S. Costa Junior).

inequality and health outcomes, including cardiac conditions (Kim, Kawachi, Vander Hoorn, & Ezzati, 2008; Dewan et al., 2019).

The blood pressure is defined in technical terms as a result of cardiac output versus peripheral vascular resistance, but its composition depends on certain risk factors; some of which have relations with economic development and demographic features. The intrinsic factors are the genetic predisposition, age, gender and race (Colhoun et al., 1998). The extrinsic factors that affects it negatively are the lack of exercise, poor diet, obesity, excess salt, alcohol abuse, smoking and stress (Colhoun et al., 1998; Braveman et al., 2005; Conen et al., 2009), which are also related to socioeconomic status (Kim et al., 2008). In poor countries with an increase in income, there is a tendency to consume goods and services not previously available widely such as more carbohydrates, red meat, industrialized food, alcoholic beverages, and cigarettes (Burkitt, 1973). There is a higher consumption of kilocalories per capita per day as one has more income available for food consumption or has access to novel food products (Dragone & Ziebarth, 2017); people eat more but not necessarily better. Healthy foods (e.g., non-transfats, reduced saturated fat and healthy oils) are generally more expensive and not commonly available for low-income people (Fogel, 2004; Danaei et al., 2013; Banerjee, 2013; Chow et al., 2013; Ortega et al., 2013). Poor countries and poorer income groups also have less access to good health services, which may affect the access to preventive measure to reduce the risk of cardiovascular diseases. On the other hand, the poor also has a low use of individual motorized modes of transport, and large part of the population uses non-motorized modes (e.g. walking or cycling) (Gwilliam, 2003; Ahmad & Puppim de Oliveira, 2016), which may provide some regular physical activity. As countries and certain groups of the population become richer, they have more resources to invest in health services, but their diets and life styles also change, not always in a healthier direction. For example, as India develops, richer households have higher chances to present individuals with high blood pressure and cardiac conditions (Barik, Desai, & Vanneman, 2018). Thus, economic development can both contribute to minimize certain cardiac risk factors and exacerbate others.

This study adds to the efforts to assess the impact of economic development on certain health outcomes. We use the male systolic blood pressure (SBP) as the health indicator. SBP is commonly used for individual and public health management. Abnormal SBP can be a serious concern for a person or society as it is a risk factor for cardiovascular and kidney diseases (Danaei et al., 2014), with consequences not only for the population's health conditions and longevity but for public and private expenditure in health care (Lee & Kim, 2008; Danaei et al., 2013; Vallejo-Torres & Morris, 2013 Woolf et al., 2015). Moreover, cardiovascular conditions can increase the risk of a person in epidemic outbreaks. For example, people with cardiovascular disease are at a higher risk of getting severe COVID-19 disease (WHO, 2020). Cardiovascular diseases have also a huge impact on productivity and the economy (Leal, Luengo-Fernández, Gray, Petersen, & Rayner, 2006), which can economically justify certain measures to subsidize health care. Thus, economic growth and health present a two-way relationship. Sustained economic growth can lead to more investment in health, and consequently better health conditions. On the other hand, improved health of the population positively impacts labor productivity and human capital formation (Atun & Gurol-Urganci, 2005).

However, we ask the following broad question, which is not consistently answered by the literature: is there any recognizable shape in the trends relating blood pressure and countries' income? Several studies identify certain trends in the risk factors as societies develop but they are not conclusive on the relation between GDPPC and blood pressure. For example, one study pointed that national income had a positive correlation with SBP among other

risk factors in 1980 but the slope of this association became negative for women in 2008 (Danaei et al., 2013). Mean blood pressure seems to have significantly dropped in high-income western countries between 1975 and 2015, but it rose in other parts of the world, particularly in developing countries, such as many in sub-Saharan Africa (NCD, 2017). Other research outcomes identify trends in cardiac conditions among different social groups or races in a certain country (Barik et al., 2018). There are also studies that provide insights at the micro perspective, looking at the relation between SBP and education, access to health services and professional categories (Conen et al., 2009). They are important to identify how different contexts and development factors affect blood pressure, but there is no study that provides a consistent macro perspective trend between an economic development indicator and blood pressure. This relation is relevant to justify investments in health at the early stages of development in order to avoid cardiac problems in the future and their consequences on human development. In this regard, a crucial point for understanding how to improve public health in the development process is what an increase in income of countries means for the general health of their populations, particularly blood pressure (SBP) in this research. Thus the contribution of this paper is to identify a general relationship between economic development and blood pressure, as the existing studies are not conclusive.

The concept of the Kuznets Curve seems relevant to be tested in this context, as some studies already point rise and fall of blood pressure with different national incomes (Danaei et al., 2013, 2014; NCD, 2017). Simon Kuznets developed a breakthrough work on the relations between economic development and socio-economic indicators. Using empirical data, he was the first to describe the relationship between inequality and income, known as the 'Kuznets Curve' (Kuznets 1955, 1976). Later on, though the original curve has been contested (Atkinson & Brandolini, 2010), similar curves were noticed when plotting economic development and different forms of environmental degradation, such as air pollution or deforestation, defining what is called the 'Environmental Kuznets Curve' (Grossman & Krueger, 1994; Stern, Common, & Barbier, 1996; Bhattarai & Hammig, 2001; Baland, Bardhan, Das, Mookherjee, & Sarkar, 2010). Kuznets curves have been determined for child labor (Kambhampati & Rajan, 2006) and tested for material use and carbon intensity (Pothen & Welsch, 2019; Roberts & Grimes, 1997). Moreover, empirically, per capita income can be associated with different environmental and socio-economic indicators, which in turn are related to health (Gangadharan & Valenzuela, 2001; Soares, 2004). Kuznets-like curves have been identified for certain health parameters such as injuries and life expectancy (Bishai, Quresh, & P. James P & Ghaffar A. , 2006; Clark, 2011), and obesity (Greco & Rotthoff, 2015). Concentration indices as a measure of health inequalities have also been observed to show a Kuznets' curve behavior (Costa-Font, Hernandez-Quevedo, & Sato, 2018). Thus, we decided to check whether the relation between blood pressure and GDPPC follow a trend like a "Heart Kuznets Curve". If it follows, what would be the measures to tunnel through the curve and avoid the heart effects of economic development? For answering those questions, we evaluated the relationship between per capita GDP (GDPPC) and Systolic Blood Pressure (SBP) of men's populations, as an indicator of health.

2. Methodology

We assessed public time-series databases for countries, which contains compiled indicators of blood pressure and economic conditions in several categories. In particular, two main variables were chosen for this study:

- 1) The mean systolic blood pressure (SBP) of men's population (mmHg), age standardized mean (ICL, 2018).
- 2) Nominal gross domestic product (GDP) per capita (GDPPC) in American dollars (US\$), in constant 2000 prices (The World Bank, 2018).

We collected data from 1980 to 2008 from these two different databases at Gapminder (Gapminder, 2018). We used this period because, while the dataset for GDPPC spans for a wide range of years, the historic series of SBP of men's populations in the public database we used is limited to 1980 to 2008 (Gapminder 2018).

The mean SBP of the male population, age standardized mean counted in mm-Hg, came from the database of the Global Burden of Metabolic Risk Factors of Chronic Diseases Collaborating Group hosted at the School of Public Health, Imperial College (ICL, 2018). The mean is calculated as if each country had the same age composition as the world population, what minimize the aging bias. Regarding the use of the SBP and its mean value, it is worth noticing that: (i) systolic blood pressure has been a better predictor of future events with high accuracy compared to diastolic blood pressure (Sever, 2009); and (ii) reference studies use the mean as the reference of comparison between demographics and geography (NCD, 2017; NCD, 2018).

The GDP data comes from the World Bank's World Development Indicators and represents the Gross Domestic Product per capita (GDPPC), nominal in constant 2000 US\$ prices. We used nominal GDP instead of Purchasing Power Parity (PPP) as the estimations of the former seems less controversial for long periods (Taylor & Taylor, 2004). Thus, the inflation, but not the differences in the cost of living between countries, has been taken into account (The World Bank, 2018). In order to categorize countries, we used the GDPPC average of four years, namely 2008, 2009, 2010 and 2011. The country income categories were defined as: (a) low income countries: GDPPC < US\$ 1,000; (b) lower-mid: GDPPC ranging from US\$ 1,000 to US\$ 4,000; (c) upper-mid: GDPPC ranging from US\$ 4,001 to US\$ 12,000; (d) high: GDPPC > US\$ 12,000 (The World Bank, 2018). We discarded countries with missing data and kept only countries with a minimum number of 27 consecutive observations of both variables, which resulted in a dataset of 136 countries (see the list of countries by categories of GDPPC in Table 1 in Annex I). We utilized R (v3.6.2) and Python (v3.7) languages as the tools for data formatting, transformations, visualization, statistical analysis by Pearson's correlation (r) and regression analysis. Built-in regression functions in R were utilized. In addition, we relied on open-source libraries: *pandas* (McKinney, 2010), *ggplot2* (Wickham, 2016) and *seaborn* (Waskom, 2018).

When applicable, z-scores on time-series data was used. This corresponds to series transformation of the series $\{x_i\}$ into another series $\{z_i\}$ and is given by

$$z_i = \frac{x_i - \bar{x}}{s_x}$$

where \bar{x} and s_x correspond to the mean and sample standard deviation of $\{x_i\}$, respectively. For the sake of completeness, Pearson's correlation r_{xy} of series $\{x_i\}$ and $\{y_i\}$, both with n elements, is calculated by

$$r_{xy} = \frac{\sum_{i=1}^n (x_i - \bar{x})(y_i - \bar{y})}{s_x s_y}$$

where s_x and s_y correspond to the sample standard deviation of $\{x_i\}$ and $\{y_i\}$, respectively.

Nevertheless, the choice of any research methodology has its limitations. In this case the following limitations can be identified with their justifications: (i) Other risk factors could have been utilized. However, measurements of SBP represents one of the easiest, most

inexpensive and widespread exams, when compared to other cardiovascular risk factors that require blood tests (e.g., diabetes). This allowed us to analyze longer time series for a large number of countries. (ii) a descriptive statistic approach is used instead of multiple regression analyses (with multiple explaining factors), since it provides a simpler, clear and visual evidence of our findings. A faceted approach, by GDPPC-based country segmentation was used to achieve the outcome objectives. (iii) restriction to male population in the sample. Men are more prone to hypertension than women in similar ages and, when affected by this condition present a greater blood pressure load on the organs (Eison, Phillips, Ardeljan, & Krakoff, 1990; Reckelhoff, 2001). Thus, we decided to take male SBP as the population risk factor since it is a more stringent scenario. Nevertheless, these questions should be further investigated in longitudinal population-based analyses in future studies.

3. Results: The 'Heart Kuznets Curve'?

In general, GDP per capita (GDPPC) increased over the years for almost all the countries and most of the countries had significant changes (increase or decrease) in SBP, with fewer countries with a neutral variation (only 18 observations where $-0.2 < r < 0.2$). Fig. 1A shows the relation between GDPPC and SBP for a sample of 16 countries, which are representative of their income categories. The different colors represent the GDPPC groups and dot sizes represent years (larger dot closer to 2008, smaller dot closer to 1980). Fig. 1A was our first plot, which motivated us to pursue further investigation of these associations for other countries, as it shows a trend of a Kuznets curve. In Fig. 1B, we grouped the 136 countries in 20 different bins classified by r -value. Furthermore, we sub-grouped each bin according to four different GDPPC groups and we utilized the same color cue for GDPPC group as in Fig. 1A.

We observe negative correlations between GDPPC and SBP for high income countries as also shown in recent studies (NCD, 2017). All countries with high GDPPC presented $r < -0.5$, except three: United Arab Emirates, Brunei and South Korea. Moreover, for the range $-1.0 < r < -0.9$, we notice exclusively high GDPPC countries. In contrast, low GDPPC countries concentrates in the right side of the histogram, with more instances of positive correlation than negative. Thus, we can infer that there is a positive correlation (increase GDPPC, increase SBP) in low-income countries, and a negative correlation in high-income countries (increase GDPPC, decrease SBP).

Thus, we decided to analyze the scores for all 136 countries in the chosen time range (1980–2008). Fig. 2 shows the z-score of the GDPPC and SBP for each one of GDPPC groups. This transformation was necessary to evaluate the common trends per group, given that each country showed different spans across each variable. For example, Mozambique, Uganda, Sudan and Bhutan have different SBP spans (see Fig. 1A). All countries are plotted, along with a fitted linear regression line and 95% confidence interval, and respective p-values. The z-score allows us to normalize country variables, in order to capture the most dominant trend concerning each group. We observe that there is a monotonic trend on the line inclination, as we traverse the GDPPC groups from low to high, resembling a Kuznets curve; what we call 'Heart Kuznets Curve' (see an illustration of it in Fig. 5B).

In order to further discuss the steepness of the SBP, we chose a subset of countries variation, where the effects on general population are more detrimental. Fig. 3A displays the increase in SBP according to GDPPC, only for countries with positive Pearson's correlations. The calculated coefficient per country denotes the SBP increase in mmHg for each additional US dollar in GDPPC. Fig. 3B shows the histogram of the regression coefficient for the GDPPC groups as defined above. Fig. 3B indicates that lower GDPPC countries showed a sharper increase in SBP per dollar of increase in

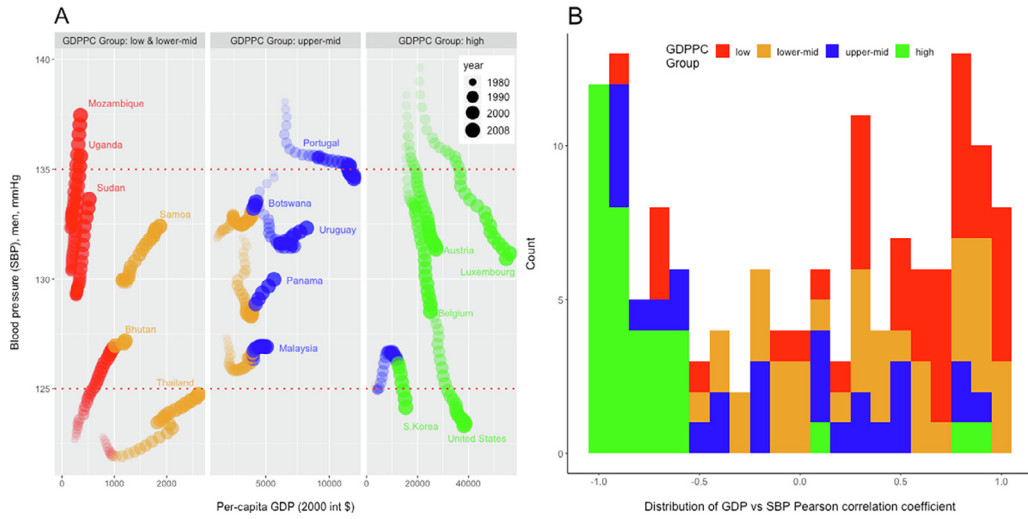


Fig. 1. A (left): Evolution of men's systolic blood pressure (SBP) and gross domestic product per capita (GDPPC) through time. B (right): The distribution of the Pearson's correlation for men's systolic blood pressure (SBP) and gross domestic product per capita (GDPPC) for all 136 countries.

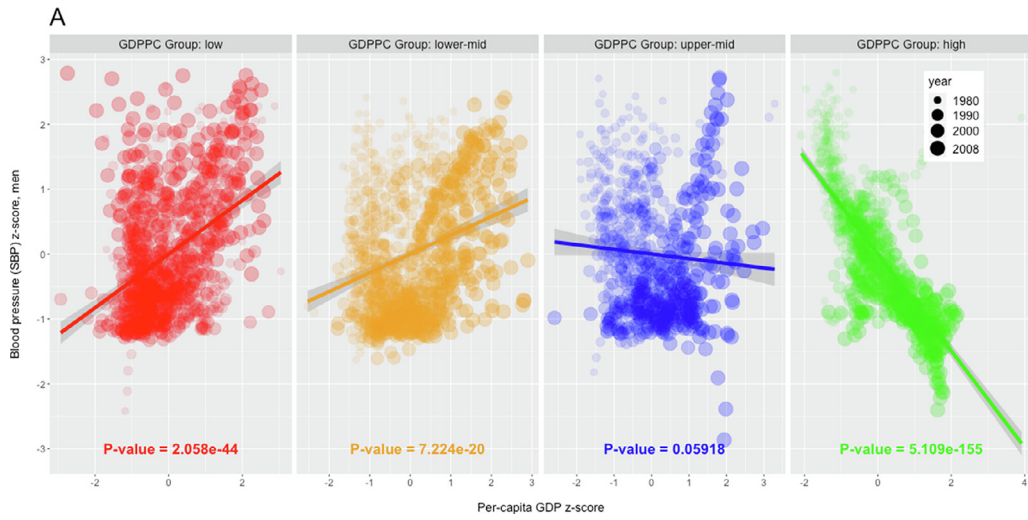


Fig. 2. Z-scores for men's systolic blood pressure (SBP) and gross domestic product per capita (GDPPC) faceted by GDPPC group. Linear regression with 95% confidence interval and p-values. All 136 countries plotted.

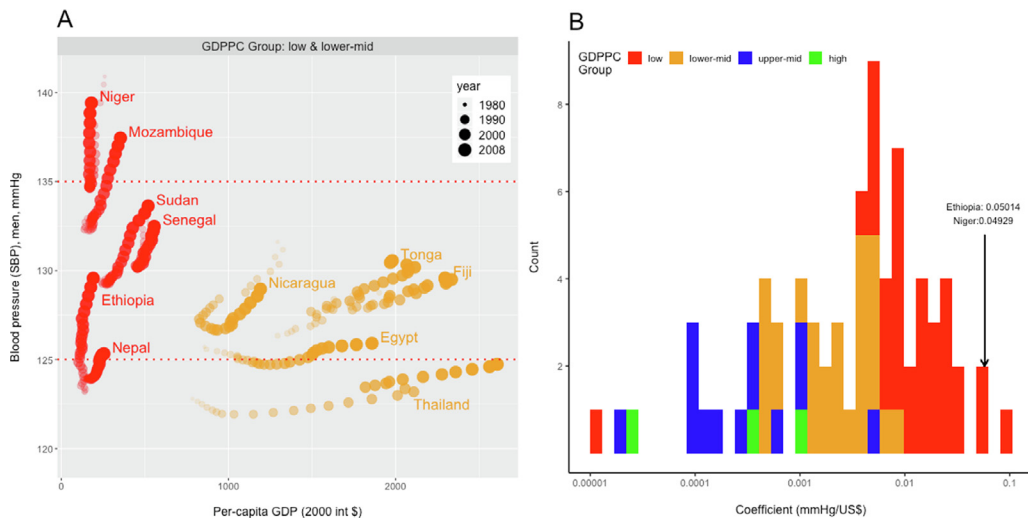


Fig. 3. A – Increase of SBP according to GDP, only for countries with positive Pearson's correlations; B – Distribution of positive coefficients by country.

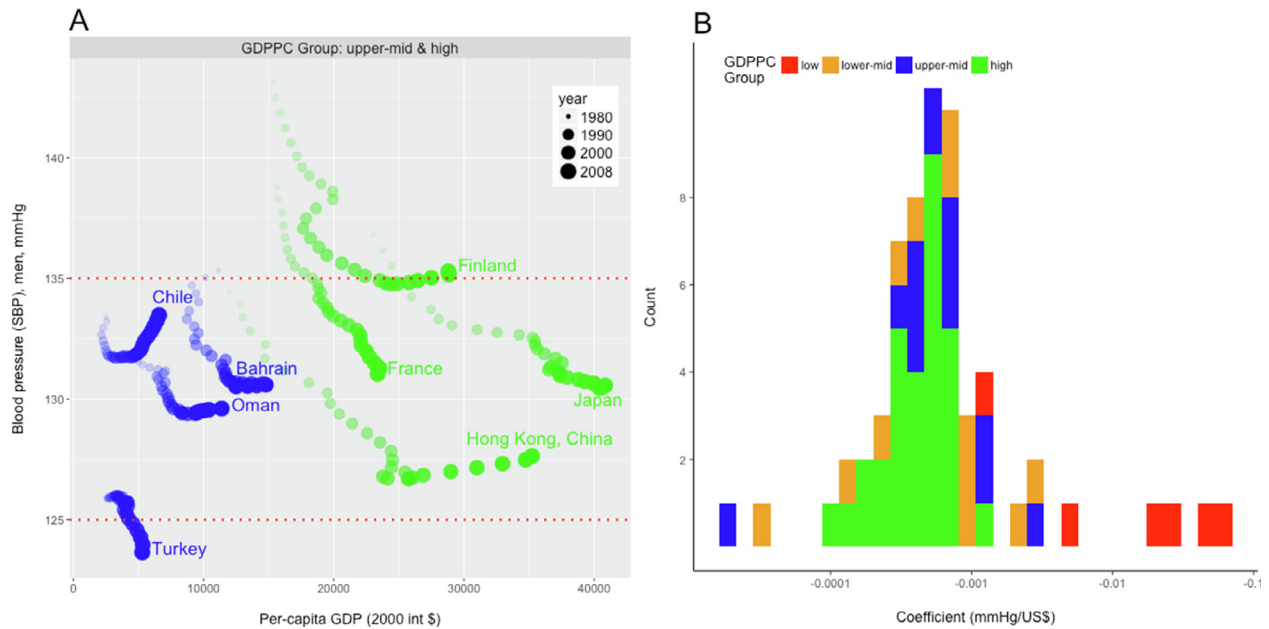


Fig. 4. A – Decrease of SBP according to GDP, only for countries with negative Pearson's correlations; B – Distribution of negative coefficients by country.

GDPPC, when compared to higher income countries. In poorer countries, the mmHg increase is even steeper. Countries that had very low income (GDPPC below US\$500 in 1980) such as Mozambique, Uganda and Sudan experienced a steeper increase in SBP, around 5 mmHg during the analyzed period. For example, Ethiopia had a coefficient of around 0.05 mmHg/US\$, so for each additional US\$1 dollar in GDPPC, the SBP increased 0.05 mmHg. On average, for US \$100 increase in GDPPC, a 5 mmHg rise in SBP is observed. In contrast, for the same GDPPC increase, a gentler rise was observed for countries with slightly higher GDPPC, such as Egypt and Fiji, where the SBP increased less than 2mmHg throughout the entire time series. For example, Nicaragua showed a coefficient of around 0.008 mmHg/US\$, thus on average equivalent to a 0.8 mmHg for every US\$100 increase in GDPPC.

In several countries, GDPPC showed a steady increase along the years, which could lead us to believe that time could be the most important determinant. However, a comparison was made of the correlations of a) SBP versus GDPPC and b) SBP versus time, showing much stronger correlation with GDPPC (we provide additional results and discussions in Annex II).

On the negative correlation countries, we plotted a sample of countries in Fig. 4A and the histogram of negative linear regression coefficients in Fig. 4B. Clearly, the majority of such countries in this set belong to high income GDPPC group. However, there are few outliers with a negative mmHg/US\$ values that are low and lower-mid income countries. These are:

- (i) low: Burundi, Guinea-Bissau, Comoros, Madagascar, Zimbabwe, Ghana
- (ii) lower-mid: Colombia, Ecuador, Bolivia, Syria, Bulgaria, Morocco, El Salvador, Tunisia, Peru, Belize, Swaziland, Romania

In order to look further into this relationship, we performed a detrended correlation analysis (see Annex III). We found reasonable arguments to support our findings on the “positive slope” of the SBP/GDPPC relationship, which is related to the poorer countries. For the wealthier the trend of SBP decrease could have more influence of other factors, in addition to the GDPPC increase.

4. Discussions: What can explain the ‘Heart Kuznets Curve’?

There are many studies analyzing blood pressure and cardiovascular conditions and treatments in specific countries, ethnicities or populations (Gupta, Al-Odat, & Gupta, 1996; Ikeda, Gakidou, Hasegawa, & Murray, 2008; Fezeu, Kengne, Balkau, Awah, & Mbanya, 2010) or risk factors such as age (Rodriguez, Labarthe, Huang, & Lopez-Gomez, 1994). Early exploratory studies already identified the changes in cardiovascular conditions as countries develop and modernize (Burkitt, 1973; Trowell, 1972). Previous comprehensive studies at a global scale also exist (Kearney et al., 2005; Kim et al., 2008; Chow et al., 2013; NCD, 2017), but they generally make a longitudinal analysis aggregated by country, income inequality or region, not correlating with income per capita in a consistent manner. Our study revealed the pattern of a ‘Heart Kuznets Curve’, showing a consistent positive correlation (increase GDPPC, increase SBP) in low-income countries and the opposite in high-income countries (increase GDPPC, decrease SBP). As countries’ incomes increase SBP tends to increase up to a certain income, when the SBP tends to decline with the increase of GDPPC, as in Fig. 5B.

In this aspect, South Korea is an emblematic case of the ‘Heart Kuznets Curve’ (see Fig. 5A). It is the only country among all 136 countries in the sample that started the series as a low-mid income country in 1980 (GDPPC of US\$3,358) and ended up as a high-income country in 2008 (GDPPC of US\$15,349). Most of the countries stayed in the same GDPPC group or crossed to the next adjacent group. The increase of SBP in South Korea was observed in the initial years of our series, with a turning point of GDPPC around US \$10,000. As the GDPPC continued to increase over this point, we observed an SBP decrease in the latter years of the series. Even though South Korea’s overall Pearson’s r is neutral ($r = 0.109$), this breakdown into two different moments of the country matches earlier observations of the differences by income and reinforces the existence of the correlation and the idea of the ‘Heart Kuznets Curve’. South Korea was able to consistently provide a better income and improve their socioeconomic status and at the same time reduce SBP after certain income to reverse the rising SBP trend.

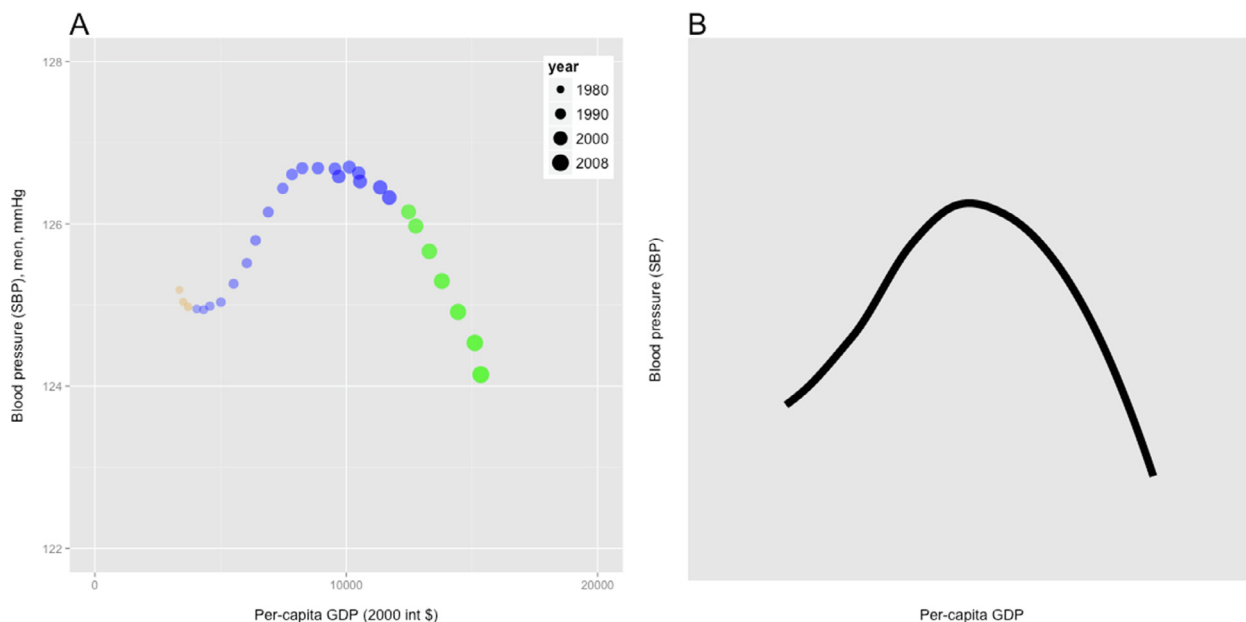


Fig. 5. A – South Korea's graph showing the relations between GDP per capita and SBP; B – Illustration of the 'Heart Kuznets Curve'.

As the incomes in a poor country increase, the diet of the population changes rapidly increasing SBP, but the health services and education for the prevention of heart problems may not improve at the same pace to offset the changes in SBP caused by changes in diet (Fuster, 2010; Danaei et al., 2013; NCD, 2017). Thus, though increase in countries' income tends to provide more access to health services, as countries invest more in health systems and individuals have more income to invest in health care, this may not compensate the negative changes in SBP until a country reaches a certain income per capita, as good quality public health care for the majority of the population takes time to be properly built and may not be a priority for policymakers at early economic development stage (Makhoul, 1984). At a certain income, it is noticed an inflection point in the SBP trend (in South Korea at around US\$ 10,000 of GDP per capita). The health system and health education improves to make access to health services (e.g., regular blood pressure checks and advice from a cardiologist or nutritionist) and preventive care (e.g., education for awareness about the importance of a more balanced diet) sufficiently more common for the population to a point to revert the rising trend in SBP (Danaei et al., 2013; NCD, 2017).

Another important determinant of SBP is physical activity, which has also some relations with economic development. Regular physical activity is associated with a substantial reduction in cardiovascular disease risks, even in groups with high risks (Humphreys, McLeod, & Ruseski, 2014). In rapid developing economies, urbanization (especially improved housing and transport infrastructure) and industrialization leads to profound shifts not only in how people eat, but how they move, work and exercise (Chow et al., 2013; Danaei et al., 2013). People tend to move from agricultural jobs, which tend to require more physical activities, to work in offices, shops or industrial plants. As individuals get richer, they also tend to move from non-motorized (e.g., walk or bicycle) to use more motorized transportation (Gwilliam, 2003; Ahmad & Puppim de Oliveira, 2016). Thus, lack of physical activities among the population seems to become more common as a country's income rises. As the prevalence of a sedentary lifestyle increases, the risk of heart problems increases. For instance, an isolated risk factor, such as obesity per se, is not the only or the most important factor to determine health. The overweight and active people can be healthier than skinny and sedentary people. The metabolically healthy overweight and well-educated people may not suffer from

conditions such as diabetes or high blood pressure (De Backer & De Bacquer, 2004; Ortega et al., 2013). Obesity has also socioeconomic causes, such as income and education, and has significant economic impacts (Cawley, 2015). Social programs, such as cash transfers, and work activity have ambiguous effects on weight (Levasseur, 2019; Feng, Li, & Smith, 2020). Health specialists suggest the implementation of recommendations regarding diet and physical activity should be a top priority for all (De Backer & De Bacquer, 2004; Chow et al., 2013; Danaei et al., 2013), including economic incentives such as taxes on unhealthy food and drinks (Cawley, 2015). As income rises over certain point, health advice and education tend to improve and make people more aware of the importance of physical activity and diet, contributing to reduce SBP (Braveman et al., 2005; Danaei et al., 2013). Thus, increase in income alone is not translated into wellness automatically. It may worsen the risk factors for cardiovascular disease, if health education and access to health care does not come together with the higher incomes. Maybe the effective access to these services happen just after a certain income turning point.

Therefore, a country with rising income does not always mean becoming a healthier country. How could we then turn income into (heart) health? Besides aggregate income, income inequality is also correlated to health outcomes and inequity in health service access (Clark, 2011; Kim et al., 2008; Baland et al., 2010; Vallejo-Torres & Morris, 2013). Reducing inequalities can widen the access to quality health services. Moreover, health information and education can transform one's behavior (Colhoun et al., 1998; Conen et al., 2009; Brunello et al., 2016), as education is an important socioeconomic factor determinant of blood pressure progression and a powerful and independent predictor (Braveman et al., 2005; Conen et al., 2009), though not stronger than GDP per capita (see Annex IV). A better income should also come with improvement in health education to reduce health risks (Conen et al., 2009; Jurges et al., 2012; Woolf et al., 2015; Lundborg et al., 2016). For example, higher income individuals reduce more the intake of fat than poorer one when receiving hypertension diagnosis (Zhao, Konishi, & Glewwe, 2013). Other factors, such as mother's education, are key for improving nutrition in their children (Behrman, Deolalikar, & Wolfe, 1988).

Socioeconomic determinants are strongly associated to health risk factors, which affects cardiovascular diseases (Conen et al.,

2009; Danaei et al., 2013). As large part of the world population is poor or has low income (Pew Research Center, 2015), in order to improve global health inequities, policy makers, including those in governments and international organizations, should develop new approaches to control these major risks for cardiovascular diseases in poorer countries in a more effective manner (Friedrich, 2014). In general, investments in health tend to address the need of the ruling privileged elites and not the wider population (Makhoul, 1984; Mobarak, Rajkumar, & Cropper, 2011), which are also more vulnerable to economic crises in terms of health (Pradhan, Saadah, & Sparrow, 2007; Shkolnikov, Cornia, Leon, & Meslé, 1998). Health problems can have a significant impact on the wealth of elders (Lee & Kim, 2008). Public programs that improve access to health services can reduce health inequalities and have significant impact on the most vulnerable (Van de gaer, Vandenbossche, Figueroa, 2013; Bagnoli, 2019). In turn, healthier societies can be more productive. Poor children with more access to public health care improve their attendance and scores (Alcaraz, Chiquiar, Orraca, & Salcedo, 2016). There are opportunities through the understanding that there is a 'Heart Kuznets Curve' for designing a better investment strategy in health care and health education that can lead to better lifestyles and reduce the risks of high SBP at early stages of development, improving the general health of the population and saving large amounts of resources in the later stages of economic development. Young adults with good cardiovascular health result in lower future costs in health care (Schiman et al., 2019). Public policies can help, informing and providing the knowledge and infrastructure to change habits (e.g., areas to exercise, opportunities for activity using non-motorized transportation). Investments in health education and services to avoid cardiovascular diseases in early stages of development can also mitigate the climbing costs of the health systems.

5. Final remarks

Income and health of populations and countries are reciprocally related. We found a strong relationship between gross domestic product per capita (GDPPC) and population's blood pressure, following a 'Heart Kuznets Curve'. In countries with low and medium income, the increase in GDPPC increased the mean systolic blood pressure (SBP) between 1980 and 2008. In rich countries, there was reduction of the average blood pressure with increase in income. Furthermore, the poorer the country is, more acute SBP jumps with rising incomes were observed.

However, the Heart Kuznets Curve is not deterministic and valid for all countries and all conditions. Kuznets Curves in other areas have been contested in several grounds, including inequality (Frazer, 2006) and environmental pollution, showing that the inverted-U shape can occur only under certain policy conditions (Ezzati, Singer, & Kammen, 2001). In health policy, removal of user fees tends to increase access to health services in countries in early stages of development, particularly for those more vulnerable (Hangoma, Robberstad, & Aakvik, 2018). Also, there are ways countries can better steward their health systems to be more effective in the use of resources and the achievement of health outcomes (Brinkerhoff, Cross, Sharma, & Williamson, 2019; Chan et al., 2019).

In addition to those pointed out in Methodology section, our study has limitations. Despite the strong correlation in some countries, we understand that within the same country there are various population groups with different socio-economic status. Countries also have distinct age distribution and ethnicities. It could be revealing to perform a deeper analysis into micro regions to better understand the behavior of individuals and groups and its relation to systemic blood pressure in different socio-political and

cultural contexts. Moreover, the relations between changes in income, changes in other socioeconomic factors and cardiovascular risk factors should be empirically tested through further quantitative and qualitative studies with multiple independent variables. We tested the correlation between education (mean years of schooling) and SBP, and though these two variables are correlated, the correlation between GDPPC and SBP is stronger (Annex IV, Fig. 8). Nevertheless, education and other factors, such as investments in health infrastructure, have an important impact on SBP, and future research could identify macro trends in those factors. A myriad of other variables, including mental and psychological factors, such as stress caused by economic instability, working conditions or vulnerability to natural disasters, also have influence in cardiac conditions, as pointed by some studies (Katsouyanni, Kogevas, & Trichopoulos, 1986; Kivimäki et al., 2006). In developing countries, other factors, such as socio-economic vulnerability or poor urban conditions, which could increase stress, could be further investigated to identify any trends (Suchday, Kapur, Ewart, & Friedberg, 2006). Thus, we suggest further studies involving several independent variables, such as using multiple regressions, for future research, as the objective of this study was limited to the macro trends in the relation between two variables (income per capita and blood pressure). Finally, studies using other proxies of economic development and blood pressure could be carried out to check the robustness of the trends we identified in this study.

Rise in blood pressure has created a growing global burden for the current and future generations (Olsen et al., 2016). It also increases the risks of the population in certain pandemics, such as the COVID-19 (WHO, 2020). The UN 2030 development agenda in its Sustainable Development Goal 3 ('ensure healthy lives and promote well-being for all at all ages') calls for a "strengthened capacity of all countries in health risk reduction and management" (UN, 2015). Despite the trends in improvement in income in most countries in the last decades, this is apparently not associated with an improvement in health education, access to health care and recommendations to prevent cardiovascular diseases by necessary changes in lifestyles in developing countries. The epidemic of cardiovascular problems and other non-communicable diseases can be prevented in many countries in the future with investments in building capacity for promoting health education and preventive services in the early stages of economic development. Thus, we could tunnel through or avoid the 'Heart Kuznets Curve' in many situations.

CRedit authorship contribution statement

Hitoshi Nagano: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Software, Validation, Visualization, Writing - original draft, Writing - review & editing. **Jose A. Puppim de Oliveira:** Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Supervision, Validation, Writing - original draft, Writing - review & editing. **Allan Kardec Barros:** Conceptualization, Validation, Writing - original draft. **Altair da Silva Costa Junior:** Conceptualization, Data curation, Formal analysis, Supervision, Validation, Writing - original draft, Writing - review & editing.

Acknowledgments

We declare no direct sources of financial assistance. We acknowledge the support of FGV for the institutional research efforts for this research to be completed. The authors declare that they have no conflict of interest.

Annex I - Countries with respective GDPPC Groups

Table 1
List of countries with respective GDP Groups.

Low (a): 39	Lower-mid (b): 38	Upper-mid (c): 26	High (d): 33
Bangladesh	Albania	Antigua and Barbuda	Australia
Benin	Algeria	Argentina	Austria
Burkina Faso	Belize	Bahrain	Bahamas
Burundi	Bhutan	Botswana	Belgium
Cameroon	Bolivia	Brazil	Bermuda
Central African Republic	Bulgaria	Chile	Brunei
Chad	Cape Verde	Costa Rica	Canada
Comoros	China	Cuba	Cyprus
Congo, Dem. Rep.	Colombia	Dominica	Denmark
Cote d'Ivoire	Congo, Rep.	Gabon	Finland
Ethiopia	Ecuador	Grenada	France
Gambia	Egypt	Hungary	Germany
Ghana	El Salvador	Latvia	Greece
Guinea-Bissau	Fiji	Malaysia	Hong Kong, China
India	Georgia	Malta	Iceland
Kenya	Guatemala	Mauritius	Ireland
Kiribati	Guyana	Mexico	Israel
Lesotho	Honduras	Oman	Italy
Liberia	Indonesia	Panama	Japan
Madagascar	Jordan	Portugal	S.Korea
Malawi	Marshall Islands	Saudi Arabia	Luxembourg
Mali	Morocco	Seychelles	Macao, China
Mauritania	Namibia	Trinidad and Tobago	Netherlands
Moldova	Nicaragua	Turkey	New Zealand
Mongolia	Paraguay	Uruguay	Norway
Mozambique	Peru	Venezuela	Puerto Rico
Nepal	Philippines		Singapore
Niger	Romania		Spain
Nigeria	Samoa		Sweden
Pakistan	South Africa		Switzerland
Papua New Guinea	Sri Lanka		United Arab Emirates
Rwanda	Suriname		United Kingdom
Senegal	Swaziland		United States
Sierra Leone	Syria		
Sudan	Thailand		
Togo	Tonga		
Uganda	Tunisia		
Zambia	Vanuatu		
Zimbabwe			

Annex II - Correlation of Year/SBP and GDPPC/SBP

It can be argued that SBP increase in lower income countries is more associated with temporal trends than with the increase or decrease of GDPPC. Temporal changes could for example be associated with adoption of western diet, if we accept that globalization had such a worldwide effect over the analyzed time-frame. Thus, we decided to compare the correlation between SBP and Year with the correlation of GDPPC and SBP. Fig. 6 shows that the bulk of the countries show up above the equality line ($y = x$). Even though the values in x-axis show density spread in (-1,1) interval, y-axis values are more concentrated in the upper quadrants. In other words, the SBP's correlation with GDPPC is in general higher than time (year). Moreover, this effect is more pronounced for low income countries. To further exemplify the lesser association with time trends, we plot in Fig. 7 three low income countries, namely Niger, Mozambique and Senegal. In all, we see: (i) decreasing SBP accompanied by decrease GDPPC, followed by increase in both as time evolves; and (ii) a weak correlation with time. The correlation of these three countries are shown in Table 2. All three countries show up in the upper quadrants of Fig. 6A, where Niger and Senegal in the left hand-side.

We believe that temporal trends observed in the period, for example globalization of food culture, are less contributing factors compared with income.

Table 2
Correlation of Year/SBP and GDPPC/SBP for three low income countries.

Country	Year/SBP correlation	GDPPC/SBP correlation
Mozambique	0.811342	0.971703
Niger	-0.318765	0.700579
Senegal	-0.266864	0.704747

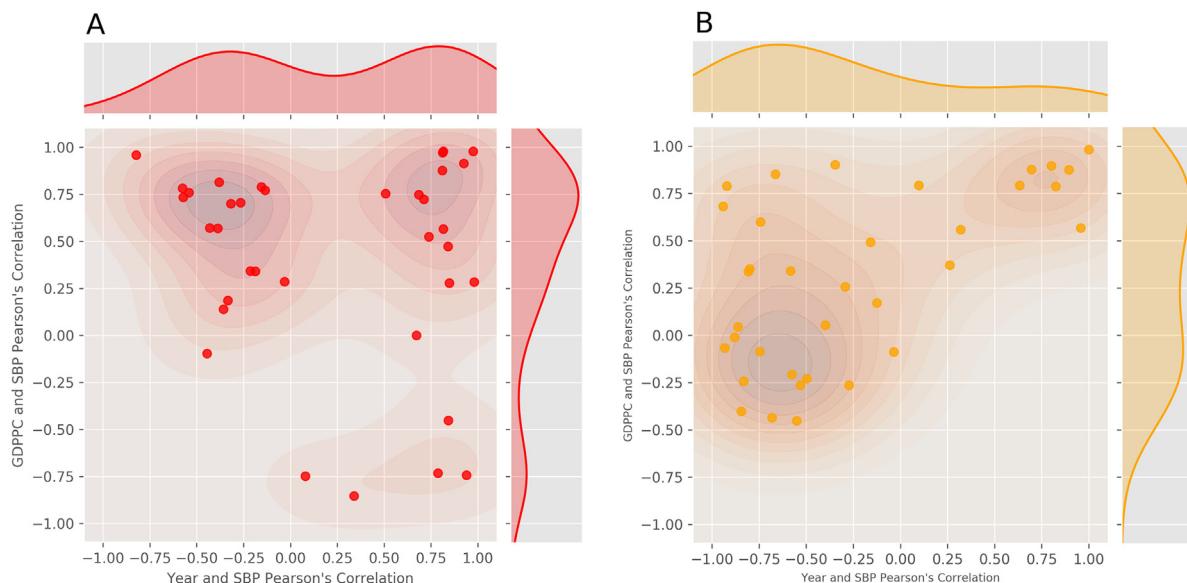


Fig. 6. Joint plots of Year and SBP Pearson's Correlation versus GDPPC and SBP Pearson's Correlation for: A – Low income. B – Lower-mid income. Kernel density estimation also shown.

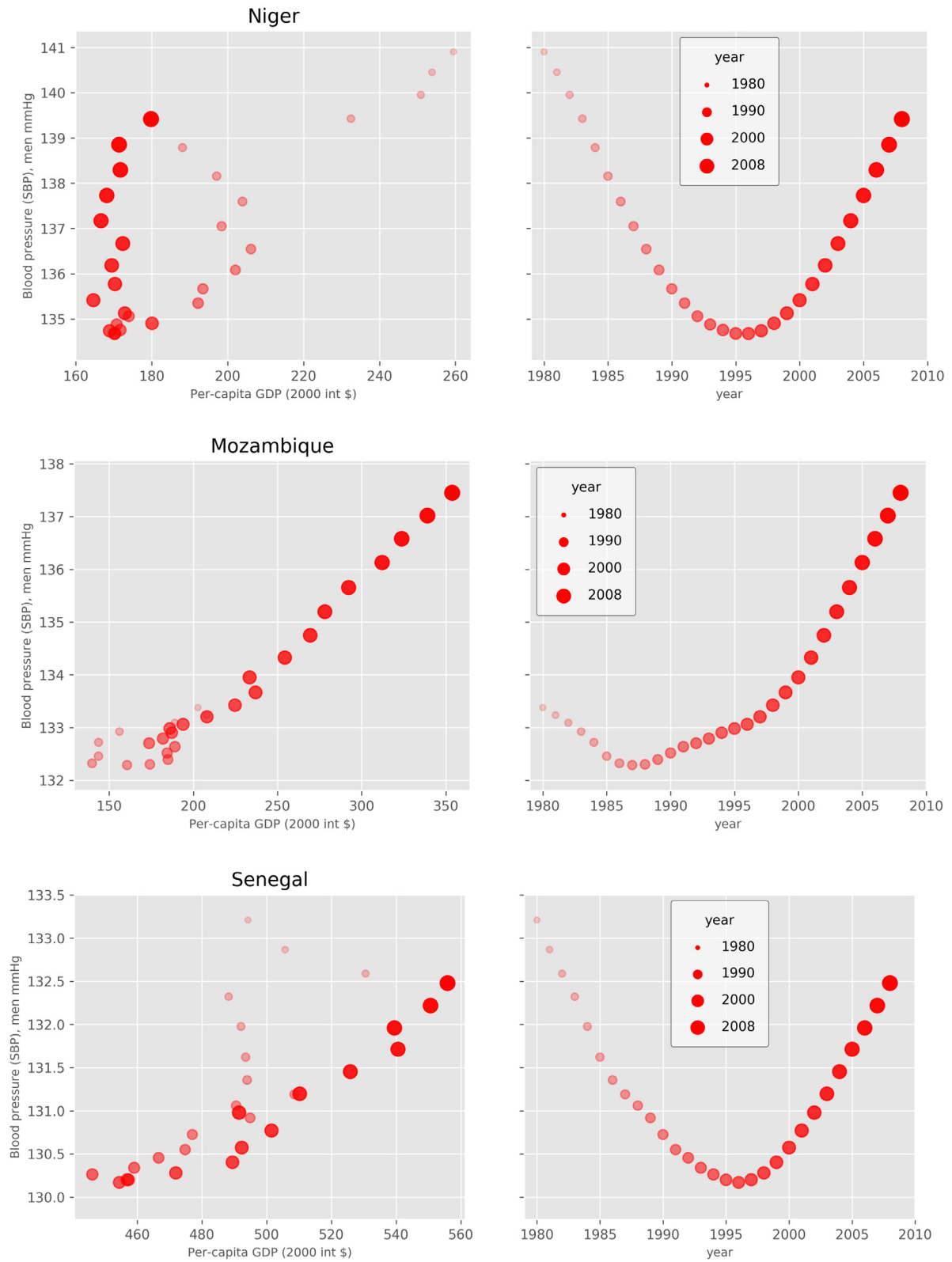


Fig. 7. Plots of SBP versus GDPPC (left) compared with SBP versus year (right) for three low income countries.

Annex III - Correlation after detrending time series

In this Annex, we report the correlations after applying first difference in both SBP and GDPPC time series (Fig. 8). We observe low and lower-mid countries with positive correlations, but not as high as the correlations observed in Fig. 1. Still, if we combine low & lower-mid countries, approximately 48% present correlation above 0.4. See Table 3.

Table 3

Summary of counts and percentages of correlations for each group.

GDPPC group	$-1 < r \leq 0$	$0 < r \leq 0.4$	$0.4 < r \leq 1$
low & lower-mid	7 (10%)	30 (42%)	34 (48%)
upper-mid	1 (4%)	15 (58%)	10(38%)
high	7 (22%)	20 (62%)	5 (16%)

On the other hand, we could not observe a pattern for the distribution for countries with higher income. In fact, those countries now show up in the positive territory and span a larger range of correlations. SBP trend downward with GDPPC increase, but the inferences that additional wealth alone may bring better health could not fully verified. In summary, from this analysis we argue that the “positive slope” portion of the Kuznets curve has a more solid reasoning, with evidence also from Annex II, while the “negative slope” part can be more influenced by other factors in place, though GDPPC still has a strong correlation with SBP.

Annex IV - Correlation of Schooling/SBP and Schooling/SBP

In this annex, we take a series of mean years of schooling (MYS) and correlates with SBP (Fig. 9). In per-country basis we compare against the GDPPC/SBP correlations. The MYS series were obtained from (Gapminder, 2018) and correspond to the mean years in school for males with 25 years or older. These include primary, secondary and tertiary education.

Other possible proxies of education data did not span several years or contained only a few points. For example, literacy rate was only available once every five years for many low income countries.

We observe higher correlations of GDPPC and SBP, with the majority of points above the $y = x$ line. This indicates a that the association of GDPPC and SBP is stronger than that of MYS and SBP.

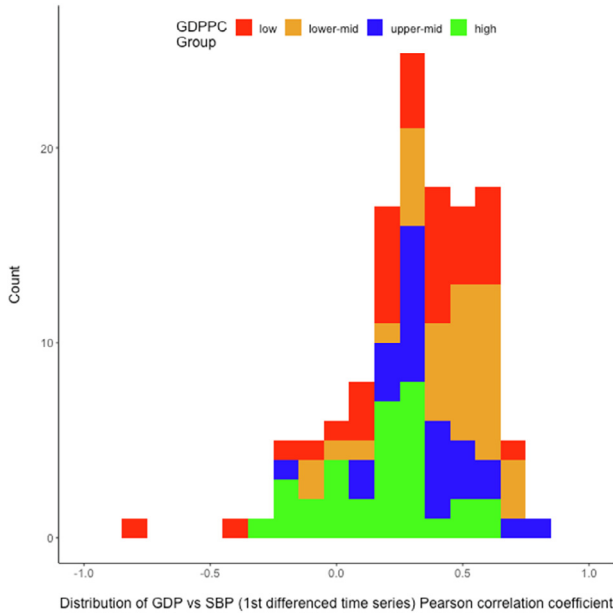


Fig. 8. The distribution of the Pearson’s correlation for men’s systolic blood pressure (SBP) and gross domestic product per capita (GDPPC) for all 136 countries – first difference applied to both series.

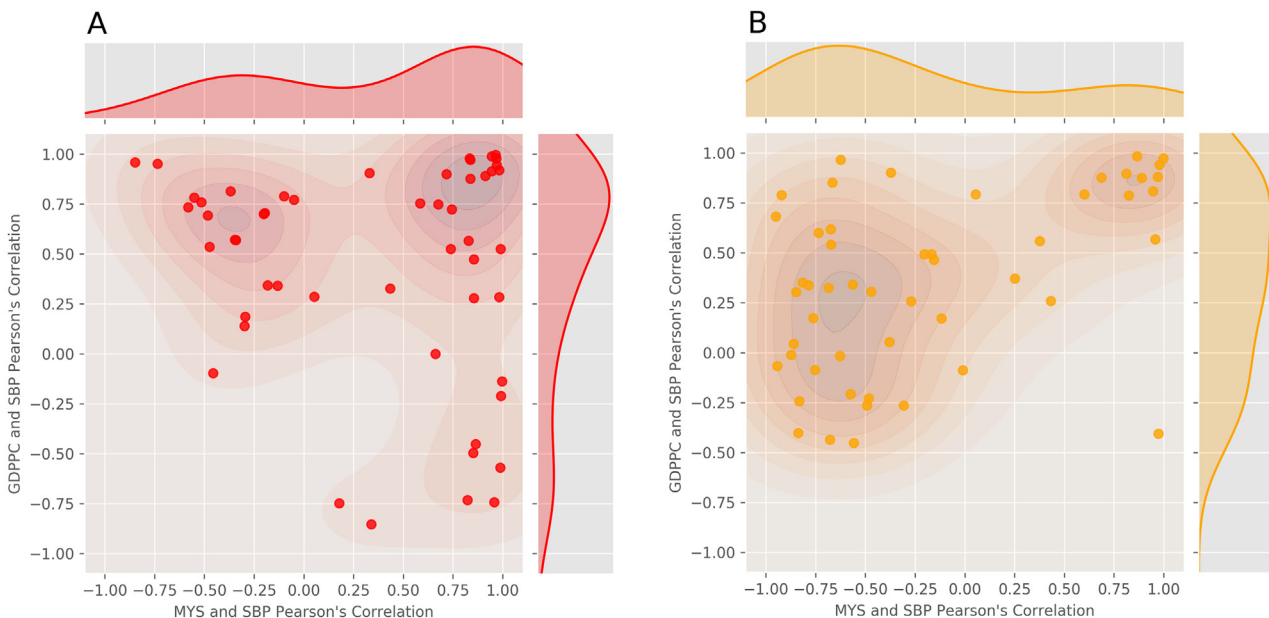


Fig. 9. Joint plots of MYS (mean years of schooling) and SBP Pearson’s Correlation versus GDPPC and SBP Pearson’s Correlation for: A – Low income. B – Lower-mid income. Kernel density estimation also shown.

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