Causality Analysis for Non-Communicable Diseases, Obesity, and Health Expenditure: Toda Yamamoto Approach

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Abstract

This study examines the causal relationship between non-communicable disease (NCD), obesity, and health expenditure in Turkey using econometric time series analysis. Data were obtained from the World Health Organization and Our World in Data for the years 1990-2019. We used a model structure capable of revealing robust causality between variables at consistent and successive time intervals to obtain reliable results. The Toda-Yamamoto econometric causality model was utilized in the E-Views 9.0 software for the analysis. The findings disclose three noteworthy results. Firstly, there exists causality from obesity to the burden of non-communicable diseases, meaning that obesity affects the proportion of non-communicable diseases in the population. Secondly, there is a causal relationship between obesity and health expenditure. Consequently, an increase in the obesity rate within society leads to a rise in the share of health expenditures in GDP. Lastly, the burden of non-communicable diseases in Disability-Adjusted Life Years (DALY) is also a determinant of health expenditures. By the obtained results from econometric causality, it is evident that NCDs, obesity, and health expenditure are interconnected as anticipated.

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Introduction

The United Nations (UN) defines non-communicable diseases as one of the most significant health challenges of the 21st century. According to the World Health Organization (WHO), non-communicable diseases (NCDs), also known as chronic diseases, are characterized by their long duration and are influenced by a combination of genetic, physiological, environmental, and behavioral factors (WHO, 2022). The primary categories of NCD include cardiovascular diseases, cancers, chronic respiratory diseases, diabetes, and mental disorders. Additionally, hyperlipidemia, metabolic diseases and obesity, neurological diseases, and musculoskeletal system diseases can be encompassed within the scope of NCDs. In recent years, lifestyle changes, environmental factors, aging, alterations in dietary habits, and increased life expectancy have contributed to non-communicable diseases such as cancer, diabetes, chronic respiratory diseases, and coronary heart disease becoming leading causes of death and disability worldwide (Alwan et al., 2010). According to WHO data, this broad spectrum of diseases is responsible for 41 million deaths annually, accounting for three-quarters of global mortality (WHO, 2022). The majority of these deaths, referred to as "premature death," occur between the ages of 30 and 70. Non-communicable diseases contribute to approximately 65.5% of total deaths worldwide and approximately 87% of deaths in the 30-70 age group in Turkey (Lozano et al., 2010; Turkish Statistical Institute, 2012). Low- and middle-income countries (LMICs) bear a greater burden of these fatalities (Suhrcke and Urban, 2006). According to Alwan (2010), cardiovascular diseases, a subset of non-communicable diseases, claim three times more lives in developing countries than HIV, tuberculosis, and malaria combined, with even higher figures observed in developed nations.

The reason NCDs are highly prioritized on the global health agenda is due to their severe consequences and our ability to enact change. It's encouraging to note that most of these diseases are "preventable," considering their significant impact on our lives. Prevention strategies focus on simple and cost-effective approaches such as promoting healthy eating, physical activity, limiting alcohol consumption, and quitting smoking. The main goal is to eliminate the main risk factors associated with NCDs. When evaluating these risk factors, disorders related to unhealthy eating habits and obesity take precedence (GBD 2019). Consequently, this study aims to experimentally establish a causal link between obesity and non-communicable diseases. It aims to determine if these diseases can be "preventable" by utilizing macro data instead of solely relying on clinical data.

The World Health Organization (WHO) defines obesity as a growing epidemic (Haththotuwa, 2020), which affects people’s mental, social, and physical well-being. This epidemic's magnitude suggests it will have social implications. Obesity, with its social components, undoubtedly has social and economic consequences (Tremmel, 2017). It is characterized by excessive fat accumulation due to an unhealthy diet and lack of physical activity. WHO 2016 data reveals that 13% of the global adult population is obese, with prevalence nearly tripling from 1975 to 2016 (WHO, 2021). In Turkey, obesity has increased from 7.6% in 1975 to 32.2% in 2016 (GHO, 2023). Obesity-related deaths in Turkey were 95.8 per 100,000 people in 2019 (GBD, 2021). Although obesity was once associated with economic power, it now negatively affects developed and developing countries, imposing significant economic burdens and healthcare expenses. The global economic cost of obesity in 2020 was close to 2 trillion USD and is projected to rise to over 3 trillion USD in 2030 and 18 trillion USD in 2060 (Okunogbe, 2022). In Turkey, the annual cost is estimated at 186 billion Turkish Lira (Orhan & Nergiz, 2014). Kortt, Longley, and Cox reported that obesity-related diseases account for 5.5% of total health expenditures in the USA (Kortt, Longley, and Cox, 1998). The escalating costs of NCDs and obesity heavily impact health expenditure.

Therefore, this study examines the causal relationship between obesity and health expenditures.

Countries' health systems are confronted with a dual burden of disease, grappling with both communicable and non-communicable diseases. As a result, non-communicable diseases pose not only a public health issue but also an escalating challenge to economic development. Concerns regarding non-communicable diseases have been mounting worldwide in recent years. Many countries have implemented prioritized action plans within their national public health policies to prevent such diseases. However, achieving results in the battle against non-communicable diseases necessitates global awareness and initiatives rather than solely national efforts. The United Nations (UN) has taken on this responsibility by organizing High-Level Meetings on the Prevention and Control of Non-Communicable Diseases in 2011, 2014, and 2018. These gatherings aim to draw the attention of heads of state and government, fostering political determination in combating non-communicable diseases. It is well-known that the proliferation and rise of non-communicable diseases within society have adverse externalities in human, social, and economic domains. These diseases are believed to diminish economic productivity and increase poverty by negatively affecting both the quantity and quality of the labor force. Consequently, diseases significantly reduce human capital stock and labor productivity, resulting in substantial income and output losses (Kutlar and Torun, 2017). Furthermore, diseases contribute to increased healthcare expenditures. This effect is particularly pronounced in the case of non-communicable chronic diseases since they often necessitate long-term, continuous care. For example, Bloom (2013) examined the economic impact of non-communicable diseases in China and India. According to the established EPIC model, the cost of the five core non-communicable diseases amounts to US$27.8 trillion for China and US$6.2 trillion for India (Bloom, 2013). Vandenberghe and Albrecht conducted a systematic review to investigate the financial burden of non-communicable diseases in the European Union. Their findings revealed that non-communicable diseases contribute to an increase in health expenditures (Vandenberghe and Albrecht, 2019). Similarly, Muka and colleagues discovered a positive association between the rising prevalence of non-communicable diseases, escalating health expenditures, and decreased well-being (Muka et al., 2015). In a separate study focusing on Germany, Schmid analyzed the direct medical costs associated with the treatment of cardiovascular diseases since 2003 and observed that these diseases exert a macro-level impact on health expenditures (Schmid, 2015). Based on these perspectives, our study sought to experimentally examine whether there is a causal relationship between non-communicable diseases and health expenditure.

Methods

The purpose of this study is to examine the causal relationship between obesity and the prevalence of non-communicable diseases in the population, as well as the causal relationship between the prevalence of non-communicable diseases and health expenditure. Our analysis used a model that can identify robust causal connections between these variables over consistent and successive time periods, ensuring reliable results.

In this research, we utilized econometric causality models. The burden of non-communicable illness represents the total disease burden measured by Disability-Adjusted Life Years (DALYs) annually. DALYs gauge the comprehensive burden of illness, accounting for both premature mortality and years lived with disability. One DALY is equivalent to one year of lost healthy life. Epidemiologists categorize the disease burden into three main groups: non-communicable diseases (NCDs) [blue], communicable, maternal, neonatal, and nutritional diseases [red], and injuries [green] (Roser and Ritchie, 2023). The data were sourced from Our World in Data.

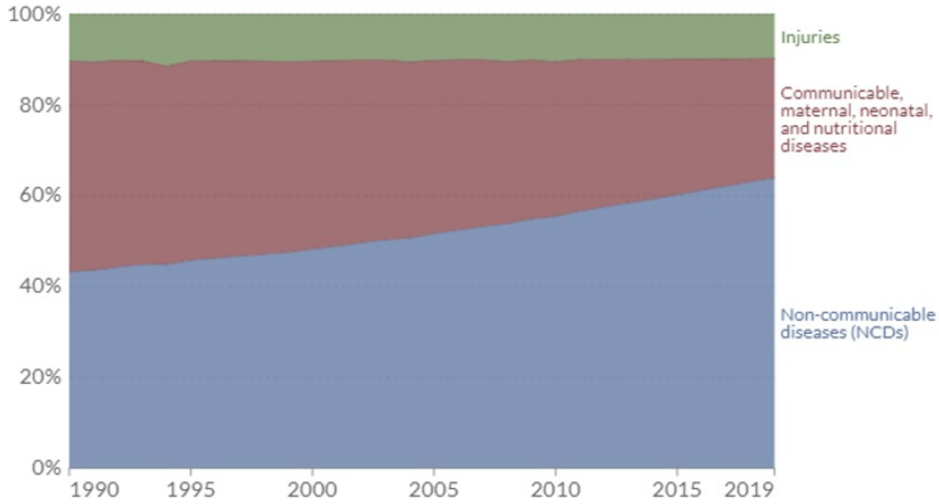

Figure 1. The total burden of disease by cause, World, 1990 to 2019

In 2019, more than 60% of the disease burden worldwide stemmed from non-communicable diseases (NCDs), while 26.35% arose from communicable, maternal, neonatal, and nutritional diseases. Injuries accounted for slightly less than 10%, as shown in Figure 1.

Obesity is typically assessed using the body mass index (BMI) scale. According to the World Health Organization, BMI is defined as: "a straightforward measure of weight relative to height, commonly employed to categorize individuals as underweight, healthy, overweight, or obese." BMI values are used to determine whether someone falls into the underweight, healthy, overweight, or obese category. The WHO establishes these categories based on the following thresholds: a BMI between 25.0 and 30.0 is classified as ‘overweight’, while a BMI greater than 30.0 is labeled as 'obese.' For our study, we used the proportion of individuals with a body mass index (BMI) equal to or greater than 30 to indicate obesity across the entire population. Data for this indicator were obtained from the World Health Organization.

Lastly, we employed current health expenditure (% of GDP) as a gauge for health expenses. The current level of health expenditure is presented as a percentage of the GDP. The estimations encompass healthcare goods and services utilized within a given year. This metric excludes capital expenditures related to health, such as infrastructure, equipment, IT, and emergency or outbreak vaccine reserves. The data was sourced from the World Bank.

We employed yearly data from 1990 to 2019 to establish the relationship between obesity (OBE), non-communicable diseases (NCD), and health expenditure (HE). To estimate causality, we utilized the E-Views 9.0 econometric software package. The summary of variable explanations can be found in Table 1.

Table 1. The explanations of the variables

Abbreviation	Variables Definition	Source
OBE	Share of people having a body-mass index (BMI) equal to or greater than 30 BMI	https://www.who.int/data/gho/data/indicators/indicator-details/GHO/prevalence-of-obesity-among-adults-bmi-=-30-(age-standardized-estimate)-(-)
NCD	The burden of non-communicable disease is the total disease burden measured as Disability-Adjusted Life Years (DALYs) year	https://ourworldindata.org/grapher/burden-of-disease-rates-from-ncds
HE	Current health expenditure (% of GDP)	https://data.worldbank.org/indicator/SH.XPD.CHEX.GD.ZS

We employed the Toda and Yamamoto (1995) causality approach, as it is currently the favored method to obtain robust outcomes on the dual causality relationship between variables (Toda and Yamamoto, 1995). The causality theory was initially proposed by Clive W. Granger in his 1969 article "Investigating causal relations by econometric models and cross-spectral methods" (Granger, 1969). According to this theory, when explaining the causality relationship between two variables, we examine whether lagged values of other variables contribute to explaining the current value of one of the variables. Specifically, the explanatory power of a model constructed to elucidate the value of a variable (Y) at time t increases when incorporating lagged values of the other variable X, referred to as the Granger cause. Sims made the first significant theoretical and empirical contribution to the Granger Causality approach in 1980 (Sims, 1980). A Causality Test has been developed to explain why Sims causality cannot be the cause of the future. Over the past 30 years, in addition to the Granger and Sims Causality Tests, other causality tests such as Toda-Yamamoto Causality Test and Panel Causality Test have been developed (Engeloglu, Meral and Genc, 2015). Granger (1969) suggested that the series should be stabilized, whereas Toda-Yamamoto (1995) does not impose such a requirement. In other words, the series are included in the analysis without sensitivity to the degree of stability. Toda and Yamamoto (1995) demonstrated that level values, even if the variables are not stationary, can be estimated and the transformed WALD (MWALD) test can be applied. The Toda-Yamamoto method is necessary when the maximum integration degree (d_{max}) of the variables in the causality study is smaller than the lag length (k). In the Toda-Yamamoto method, regardless of whether the variables are stationary or not, the model [k + (d_{max})] is estimated by adding an extra lag variable to the level of integration at the maximum integration level, and the MWALD hypothesis test is applied. The Toda and Yamamoto causality test ensures that the series contains more information and yields more accurate prediction results (Akkas and Sayılgan, 2015; Dogan, 2017; Toda and Yamamoto, 1995).

In this context, we used the Toda-Yamamoto econometric method to test causality. We investigated the presence of a causal relationship between the two variables, in other words. The research hypotheses are as follows:

- H_{0a}: *Obesity is not the cause of the burden of non-communicable disease.*
- H_{1a}: *Obesity is the cause of the burden of non-communicable disease.*
- H_{0b}: *Obesity is not the cause of health expenditures.*
- H_{1b}: *Obesity is the cause of health expenditures.*
- H_{0c}: *The burden of non-communicable disease is not the cause of health expenditures.*

- *H_{1c}: The burden of non-communicable disease is the cause of health expenditures.*

As per the Toda-Yamamoto causality approach, the variables can be elucidated through three distinct equations, as outlined below.

$$NCD_t = \beta_{0a} + \sum_{i=1}^{k}\left(\alpha_{1i}NCD_{t-i}\right) + \sum_{j=k+1}^{dmax}\left(\beta_{2j}NCD_{t-j}\right) + \sum_{i=1}^{k}\left(\theta_{1i}OBE_{t-1}\right) + \sum_{j=k+1}^{dmax}\left(\theta_{2i}OBE_{t-i}\right) + \varepsilon_{1t} \quad (1 - \text{ Hypotheses } a)$$

$$HE_t = \beta_{0b} + \sum_{i=1}^{k}\left(\alpha_{1i}HE_{t-i}\right) + \sum_{j=k+1}^{dmax}\left(\beta_{2j}HE_{t-j}\right) + \sum_{i=1}^{k}\left(\theta_{1i}OBE_{t-1}\right) + \sum_{j=k+1}^{dmax}\left(\theta_{2i}OBE_{t-i}\right) + \varepsilon_{2t} \quad (2 - \text{ Hypotheses } b)$$

$$HE_t = \beta_{0c} + \sum_{i=1}^{k}\left(\alpha_{1i}HE_{t-i}\right) + \sum_{j=k+1}^{dmax}\left(\beta_{2j}HE_{t-j}\right) + \sum_{i=1}^{k}\left(\theta_{1i}NCD_{t-1}\right) + \sum_{j=k+1}^{dmax}\left(\theta_{2i}NCD_{t-i}\right) + \varepsilon_{3t} \quad (3 - \text{ Hypotheses } c)$$

Results

Initially, we determined the maximum degree of integration (d_{max}) of the variables using a standardized Augmented Dickey-Fuller (ADF) unit root test. The results of the ADF test are shown in Table 2.

Table 2. ADF unit root test results (intercept)

	t-stat	**Test critical values**			***p***
		%1	***%5***	***%10***	
HE (Δ)	-6.338283 [0]	-3.689	-2.971	-2.625	<0.00001
NCD (Δ)	-5.270350* [0]	-3.689	-2.971	-2.625	0.0002
OBE (ΔΔ)	-17.27366* [1]	-3.699	-2.976	-2.627	0.0001

*Δ=first difference, ΔΔ=second difference *, statistically significance at 1%. The values in square brackets indicate the lag lengths determined by the SIC criteria.*

According to the results of the ADF unit root test shown in Table 2, the HE and NCD series are $_1$I (stationary when first differenced) and OBE is I_2. So the d_{max} was determined as 1 for HE and NCD causality, on the other hand, it is 2 for OBE and NCD along with OBE and HE causality.

Then, we determined the maximum integration degree of the series in the model before optimal lag length and causality analysis, and we calculated optimal lag lengths (k) for the equations. The maximum number of lags was determined by the method developed by Schwert (1988). Then, we used the information criteria to determine the optimal lag length for the equations. According to Akaike Information Criterion and Hannan Quinn Information Criterion optimal lag length is one for equations 1 and 2; and two for equation 3. Under these conditions, for all the equitation's $k+d_{max}$ is determined 3. So, the causality relation test results between variables, based on models described by equations (1), (2), and (3) with $k+d_{max}$ are listed in Table 3 which shows the MWALD test results.

Table 3. Toda–Yamamoto approach-based causality test results

Hypothesis	χ^2	p	Result
OBE ⇏ NCD H_0: No Causality	11.82509	0.0005**	H_0: Rejected
OBE ⇏ HE H_0: No Causality	16.841 07	<0.00001**	H_0: Rejected
NCD ⇏HE H_0: No Causality	15.04441	0.40001**	H_0: Rejected

***p value was calculated according to (k) degree of freedom.*

We have found that the initial null hypothesis, which suggests that obesity is not the underlying cause of the disease burden, has been refuted. Furthermore, our investigation has also refuted the second null hypothesis, indicating that obesity is indeed a significant factor contributing to health expenditures. Regarding the association between non-communicable diseases and health expenditures, we have not rejected the first null hypothesis, suggesting that the disease burden alone is not the cause of healthcare costs. Therefore, based on the outcomes of our causal models, we have established that there are causal relationships linking obesity to the disease burden of non-communicable diseases and to health expenditures. Additionally, we have determined that the disease burden measured in DALY (Disability-Adjusted Life Years) is a contributing factor to healthcare expenditures.

Discussion

Chronic diseases pose a significant global concern across societies, giving rise to numerous challenges such as escalating healthcare costs and declining workforce participation. Obesity is widely recognized as a key contributing factor. A study conducted in Brazil spanning the years 1990 to 2017 revealed that obesity has significantly contributed to the disease burden encompassing cardiovascular diseases, diabetes, and mortality (Felisbino-Mendes et al., 2020). Furthermore, the prevalence of obesity is known to increase with age, posing a threat to an aging world population. According to the research by Renehan et al., a 5 kg/m² increase in BMI among men was found to be associated with esophageal adenocarcinoma, thyroid, colon, and kidney cancers. In women, notable associations have been observed between BMI increments and cancers of the endometrium, gallbladder, kidney, and esophageal adenocarcinoma. Furthermore, weak associations with leukemia, multiple myeloma, and non-Hodgkin lymphoma have been documented in both genders (Renehan, 2008). Moreover, Dhawan et al. highlighted the association between visceral obesity and NCDs, specifically diabetes, hypertension, heart diseases, non-alcoholic fatty liver diseases, kidney disorders, and cancer (Dhawan, 2020).

According to the study by Anderson & Durstine (2019), exercise and physical activity play a crucial role in reducing the risk of chronic diseases. Without adequate exercise and physical activity, cardiovascular disease, obesity, type 2 diabetes, and cancer are projected to increase significantly by 2030. This trend is expected to contribute to a higher share of health expenditure in GDP while decreasing the GDP growth rate. Anakök et al. found that nearly half of the cases of Type 2 diabetes in the Turkish population were linked to advanced obesity (Anakök, 2022). Another study revealed that 80.9% of patients with a history of cardiovascular events were overweight (BMI ≥25 kg/m2), and 30% were obese (BMI ≥30 kg/m2) (Tokgozoglu, 2021).

By 2030, Wang et al. project an increase of 65 million obese adults in the US and 11 million in the UK, based on their analysis of data from these two aging countries. This rise in obesity is expected to contribute to an additional 6–8.5 million cases of diabetes, 5.7–7.3 million cases of heart disease and stroke, and 492,000–669,000 additional cancer cases in these countries. Moreover, the cumulative loss in quality-adjusted life years (QALYs) is projected to range from 26 to 55 million. The associated medical costs for treating obesity-related NCDs are estimated to increase by $48-66 billion per year in the US and £1.9-2 billion per year in the UK by 2030 (Wang, 2011).

Based on articles from a review, it is estimated to account for approximately 0.7% to 2.8% of a country's total healthcare costs. Additionally, obese individuals tend to have approximately 30% higher medical costs compared to those with a normal weight (Withrow, 2011). This finding is supported by Finkelstein et al.'s study, which reveals that obese patients experience 46% higher inpatient costs, 27% more doctor visits and outpatient care expenses, and 80% higher prescription drug expenditures compared to individuals with a normal weight (Finkelstein, 2009).

The situation remains unchanged when considering not only obesity but also non-communicable diseases (NCDs) in general. The projected global economic cost, calculated using the Value of Statistical Life (VSL) approach, is expected to increase from 22.8 trillion USD in 2010 to 43.3 trillion USD in 2030 (Bloom, 2011). According to Vandenberghe and

Albrech's review, the four major NCDs within the European Union account for at least 25% of healthcare expenses, equivalent to around 2% of GDP (Vandenberghe & Albrech, 2020). Turkey also faces a significant burden of NCDs, with 30% of public health expenditures in 2016 attributed to these conditions, which is 69.7 billion TL and representing 3.6% of annual GDP (Kontseyeva, 2018). Another study conducted a 10-year forward simulation in Brazil, suggesting that implementing specific health policies could potentially reduce these expenditures from 3.3% to 1.2% by 2030 (Nilson et al., 2022).

Conclusion

Our study emphasizes the significance of providing evidence to demonstrate the growing risk of non-communicable diseases resulting from obesity, which in turn leads to reduced workforce participation due to increased healthcare expenses and disabilities. Additionally, it is essential to conduct new predictive simulations that account for the aging population worldwide. As the number of studies increases, we anticipate a clearer understanding of global health policy trends. Moreover, we firmly believe in the critical importance of leveraging social media, employing dietitians, and emphasizing the significance of anti-obesity campaigns and incentivization efforts.

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