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Cardiovascular disease mortality and economic factors: Empirical evidence from seven Southeast Asian countries

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Abstract

This thesis examines the relationship between economic factors and cardiovascular disease (CVD) mortality across seven Southeast Asian countries: Vietnam, Thailand, Malaysia, Singapore, Philippines, Indonesia, and Laos. It builds upon existing literature with the hypothesis that economic factors such as GDP per capita, current health expenditures, and Excise Tobacco Tax influence CVD mortality in an inverse U-shaped relationship, or a "Kuznets Curve." This relationship indicates that as economic factors improve, CVD mortality initially worsens until reaching a certain threshold, beyond which health outcomes begin to improve. The study utilizes a log-log regression model over data spanning from 2000 to 2019, incorporating both Fixed Effects and Random Effects specifications. The results confirm an inverse U-shaped relationship between GDP per capita and CVD mortality and a similar pattern for current health expenditures. However, Excise Tobacco Tax did not follow this pattern, suggesting either a linear or U-shaped relationship with CVD mortality. This outcome is explained by a theoretical model in which an agent maximizes their utility and allocates income between health and other consumption. This study provides value to the health economic landscape by extending the application of economic theories to public health in Southeast Asia. Furthermore, it also provides a theoretical and empirical foundation for policy interventions aimed at optimizing health outcomes through economic factors.

Contents

Nomenclature

AIC Akaike Information Criterion

BIC Bayesian Information Criterion

CHE: Current Health Expense

CVD: Cardiovascular disease

FE: Fixed Effects

GDP: Gross Domestic Product

LMIC: Low-middle income countries

RE: Random Effects

SEA: South East Asia

1 Introduction

Cardiovascular disease (CVD) is one of the world's most deadly killers. For the past decades, it has been the leading cause of morbidity and mortality globally. Despite being commonly referred to as the "Western disease", CVD was responsible for 18.6 million deaths globally, with up to 58% of these deaths in Asia in 2019 (Zhao, 2021; Ezzati et al., 2005). Furthermore, while also commonly referred to as the "disease of affluence," four out of five CVD deaths occur in low- to middle-income countries (LMICs). Adding to this problem, advancements in treatment and prevention are mostly happening in wealthy countries, making it harder for less affluent regions to acquire the most advanced technologies for research, prevention, and treatment (Federation, 2023). CVD not only individuals' physical and mental health are affected, but its economic cost of is surmountable, diminishing economic productivity and overwhelming healthcare systems globally. The issue is especially problematic in Southeast Asia (SEA), where many countries are classified as low- to middle-income. Therefore, these countries often do not have adequate access to adequate preventative and treatment care (World, 2024). This inadequacy can be attributed to poverty, lack of education in rural areas, and insufficient health infrastructure (Nishtar, 2002; Kalra et al., 2017). With rising demands for proper care and not enough quality supply, CVD is becoming a growing problem in SEA as evidenced by Figure 1 in the Appendix. As of 2023, CVD is responsible for one-third of all annual deaths in SEA, equivalent to approximately 4 million people (Federation, 2023).

Compounding on the lack of quality care in these regions, the rising prevalence of risk factors specific to the region such as dietary habits, smoking, the aging population, and other genetic factors/disorders contribute to the issue. Traditional diets are being replaced with processed fast foods, leading to unhealthy eating habits. This could be one of many reasons that SEA is suffering from increased rates of obesity and dyslipidemia (Federation, 2023). Additionally, the prevalence of smoking in SEA is alarmingly high compared to global rates, though its prevalence is significantly diminished compared to a decade ago (WHO, 2022). The aging population in Asia is also more prone to cardiovascular conditions (Zhao, 2021). Furthermore, genetic factors specific to SEA individuals intensify these risks. These include increased insulin resistance and elevated lipoprotein(A) levels, which can heighten coronary heart disease (Nishtar, 2002). These factors compound to raise the CVD incidence in SEA. To tackle this issue, the governing bodies in SEA must prioritize funding policies and campaigns that seek to reduce CVD risk factors. Since the region is comprised of mostly developing countries, effective budget allocation of health expenses on a macro level can significantly increase the availability and quality of CVD healthcare services. Therefore, this paper aims to analyze the empirical relationship between cardiovascular disease outcomes and several key economic factors, showing how CVD results differ in countries with different economic circumstances. Furthermore, the mechanisms in which these variables interact with each other will also be highlighted.

Given this context, the research will be guided by the following question:

What is the relationship between cardiovascular disease outcomes and economic factors in selected countries in Southeast Asia?

Specifically, this thesis will collect and analyze data on CVD deaths per capita and several

economic factors across seven selected SEA countries from 2000 to 2019. It will examine the model of an inverse U-shaped relationship, established by Spiteri and Von Brockdorff (2019), between GDP per capita and CVD mortality within the context of SEA. The same will be done on two other economic factors, current health expenditures (CHE) and tobacco taxation. By analyzing these aspects, the thesis provides insights into how economic factors influence cardiovascular health in SEA. Furthermore, the study's findings will contribute to the existing academic theories on the Kuznets Curve for CVD and offer evidence-based recommendations for policy improvements, applicable both in the SEA region and in similar contexts globally.

2 Literature review

While many studies have explored the relationship between economic factors and health outcomes, not many have specifically focused on the relationship between economic factors and CVD outcomes. Additionally, the theoretical landscape explaining such a relationship is also not well established and backed by empirical panel data. Finally, the regions of interest of previous scholars were often North America and Europe, neglecting the severity of the problem in Asia. Even fewer papers have investigated the SEA region, which has a unique economic and health landscape. This literature review section will provide an overview of relevant studies, highlighting their key findings and identifying gaps that this thesis aims to address.

This thesis builds upon foundational theoretical works that established significant relationships between health outcomes and various other economic variables. The most important contribution to health economics, in general, is the influential paper by Grossman (1972), which introduced the concept of health demand and paved the way for much future research on the link between health and the economy. For instance, Bhargava, Jamison, Lau and Murray (2001) extends upon the Grossman model and demonstrates that adult survival rates positively influence economic growth, highlighting the importance of investing in health infrastructure. Another example of Grossman's impact on health economics is the paper by Bloom, Canning and Sevilla (2004), which used a production function model to show that good health has a sizable and statistically significant effect on aggregate output or economic productivity. The most relevant foundational work to this thesis, however, belongs to Simon Kuznets, who proposed an inverted U-shaped relationship between income-related (health) inequality and economic development (Kuznets, 1995). In exploring the relationship between health outcomes and economic growth, researchers have been relying on his framework, looking for the existence of the same inverse U-shaped model outside of the inequality context. The expanding body of empirical literature frequently references his theoretical concept and coins the inverse U-shaped relationship as the "Kuznets curve". For instance, Ezzati et al. (2005) found that body mass index and cholesterol levels rapidly increased with national income up to a certain threshold, then tapers off after. Though the term "Kuznets curve" was not explicitly mentioned, the result describes the phenomenon exactly. A decade later, Grecu and Rotthoff (2015) identified an "Obesity Kuznets curve", suggesting that while economic growth initially leads to higher obesity rates, it eventually results in better obesity outcomes due to individuals having more budget to invest in their well-being.

With regard to CVD specifically, researchers have empirically identified the connections between CVD variables and economic factors and used theoretical models to justify these findings.

Iqbal (2012), for example, used panel data to show that CVD hospitalization bears a great financial burden for individuals without insurance in LMICs. It can be inferred from the paper that with better economic development and policies, CVD treatment could have been more effective and would not have a significant weight on these countries' health systems. Regarding the variable of CHE, the existing literature has not thoroughly examined the specific relationship between CHE and CVD mortality rates. Even the broader topic of Public Health Expenses and CVD rates has been largely ignored. The relationship of Excise Tobacco Tax and CVD rates, however, has been thoroughly investigated in other Asian regions.Wu et al. (2021) paper concluded that Beijing's tobacco control policy package averted around 13% of hospital admissions for CVD among their sample. The study conducted by Basu, Glantz, Bitton and Millett (2013) also presented evidence from a microsimulation model that supports the efficacy of tobacco policies in reducing CVD rates. In the next decade, smoke-free legislation and tobacco taxation could avert one-third of deaths from myocardial infarction and stroke among Indian individuals aged 20 to 79. For the relationship of CVD with GDP, one of the most influential recent papers on the existence of a Kuznets curve in the context is by Spiteri and Von Brockdorff (2019), whose methodology has significantly influenced this thesis. The authors discovered a statistically significant inverted U-shaped relationship between economic development and CVD mortality, indicating that mortality rates initially increase with rising income levels, but decrease as income continues to grow. To mathematically explain the existence of the Kuznets Curve within this context, the authors also developed a theoretical model where an agent maximizes their utility by allocating their income between consumption and health expenses. This study will also attempt to use this mathematical model to explain the empirical findings.

This thesis contributes to the existing literature by extending the analysis to SEA, a region where the economic and health landscapes are vastly different from those in Europe, and even other Asian continents. It examines the existence of an inverse U-shaped relationship between CVD mortality rates and GDP per capita in SEA, building upon the work of Spiteri and Von Brockdorff (2019) and staying consistent with the study's theoretical framework. Additionally, this thesis explores the inverse U-shaped relationship in additional economic factors such as CHE and tobacco tax. CHE, which has not been extensively studied in this context, has the potential to bring forth impactful results that can form effective policies. Excise Tobacco Tax's effects, though has been examined in several other Asian regions, are still largely unknown in the SEA region. By incorporating these variables, the study aims to provide nuanced insights into how economic factors influence CVD outcomes in SEA.

From the review of literature, a hypotheses has been formulated for this thesis:

Null hypothesis (H_0): Economic factors such as GDP per capita, CHE per capita, and Excise Tobacco Tax do not demonstrate a "Kuznets curve" or an inverse U-shaped relationship with CVD mortality.

Alternative hypothesis (H_α): Economic factors such as GDP per capita, CHE per capita, and Excise Tobacco Tax demonstrate a "Kuznets curve" or an inverse U-shaped relationship with CVD mortality. .

3 Methodology

3.1 Description of data

The research question will be answered using quantitative panel data on several key indicators. Collected data reflects the economic factors that have effects on the CVD issue in SEA countries. The complete list and description of each variable used in this thesis, along with their sources and categories, are provided in Table 13 in the Appendix. Summary statistics for these variables are presented in Table 1.

Table 1
Descriptive Statistics

	Mean	**SD**	**Min**	**Max**
CVD Deaths per Capita	0.0017039	0.0003978	0.0010643	0.0025075
Health Expenditure per Capita	325.6357	586.0483	13	2826
GDP per Capita	8727.571	14764.79	330	64815
Obesity Prevalence per Capita	0.1374861	0.0925541	0.006173	0.4113809
Smoking Prevalence per Capita	25.19843	5.086388	13.91	33.74
Human Development Index	709.8071	109.2985	473	945
CO2 Emissions per Capita	3.559	3.184674	0.18	11.94
Diabetes Prevalence per Capita	0.039377	0.0153623	0.0202379	0.0808759
Hypertension Prevalence per Capita	32.46214	4.880212	24.9	42
CVD Prevalence per Capita	0.0456131	0.0086723	0.0316803	0.0730056
Interpolated Tobacco Use per Capita	40.45123	19.05318	2.29	63.55

The relationships estimated in this thesis total 140 observations, based on panel data from 7 selected SEA countries—Vietnam, Thailand, Philippines, Laos, Malaysia, Indonesia, and Singapore—covering the period from 2000 to 2019. The countries initially included in this study are based on the 10 member states of the Association of Southeast Asian Nations (Secretariat, n.d.). However, Brunei Darussalam, Cambodia, and Myanmar were excluded from this study due to data-related challenges. According to Murray (2022), Myanmar does not have an Operational Unit in the Ministry of Health responsible for Non-Communicable Diseases. The absence of such a unit hinders the systematic implementation and monitoring of CVD policies nationwide. The same report indicates that Cambodia lacks systematic guidelines for the management and treatment of CVD. Brunei Darussalam is not included due to data omission, with certain key variables not recorded annually. These factors are country-specific and lack suitable proxies that could be included in the econometric model for control. Therefore, the dataset is better off not including these countries as it may skew the coefficients and result in biased outcomes.

The period from 2000 to 2019 was selected based on data availability and potential externalities concerns. The SEA countries included in this study, except Singapore, have been categorized as developing countries before the 2000s and continue to be so, lacking proper data collection methods. Some data points are either inaccurate or absent before 2000. Therefore, the year 2000 is the cutoff point chosen to ensure all selected countries in the sample have developed

adequate systems for collecting social health data and expenditures (WordData, n.d.). The data cutoff in 2019 is due to concerns about the global effect of the COVID-19 pandemic on funding priorities, public health campaigns, and CVD outcomes worldwide, not only in SEA. As noted by *Pan American Health Organization* (2023), individuals with underlying conditions like CVD face a higher risk of severe COVID-19. CVD cases within the pandemic period could potentially be misclassified as COVID-19, or vice versa. During the pandemic, the SEA region in particular has also witnessed significant disruption in the provision of essential health services for non-communicable diseases (NCDs) such as cancer and CVD. This disruption has likely resulted in a detrimental impact on both the prevalence of CVD risk factors and its outcomes (Gadsden, Downey, Vilas, Peiris & Jan, 2022). Therefore, this period ensures that all the variables included in this study are available and unaffected by the global pandemic.

This thesis focuses on the dependent variable of CVD death per capita in each selected country. CVD mortality is often employed as a proxy in existing literature to evaluate the effectiveness of economic developments and campaign initiatives on the management of CVD. A prominent and most recent example is the study by Spiteri and Von Brockdorff (2019), in which the authors explored the relationship between economic development and CVD mortality rates in 27 European countries, finding significant results relevant to future EU policies.

The analysis in this paper will be divided into three sections. The first section will extend on the work of Spiteri and Von Brockdorff (2019) and test the replicability of the study's results with SEA data. The second section will address the research question by examining the effects of current health expenditures per capita on CVD mortality. Though the first section of the analysis will confirm the effects of GDP per capita on CVD mortality, narrowing down on how much SEA governments are willing to allocate their budget to healthcare will help policymakers make fitting adjustments. The amount spent on health prevention campaigns, treatment, and research is a significant determinant of public health outcomes. The last section focuses on the relationship of Excise Tobacco Tax as a proportion of Tobacco price. This variable is a proxy for how an monetary disincentive can curb the use of tobacco, one of the most significant and prominent risk factors for CVD. In a study by Zhao (2021), smoking remains the leading factor for Disability-Adjusted Life Years (DALYS) in two out of seven countries selected in this sample and its prevalence in SEA is only second behind Eastern Europe with 37.7% of the total population of the region that smokes daily in 2015. Additionally, the use of smokeless tobacco has increased significantly in recent decades, particularly in South Asia and SEA. Therefore, the result from this section will provide invaluable insights into the existing literature.

Additionally, confounding factors are incorporated in the "Extended Model" in this paper. The prevalence of CVD, which has not been thoroughly examined in existing literature, is crucial for understanding the full impact of CVD on populations and the effectiveness of preventative measures. Incorporating it into the "Extended Model" removes the inherent difference of existing CVD cases between countries, making the coefficients less biased and more robust. Another category of control variable is a country's lifestyle factors such as obesity and smoking. These are behaviors that stem from detrimental habits and are well-established risk factors for CVD. The prevalence of hypertension and diabetes is also highly important to include , as these conditions are responsible for the majority of CVD deaths and incidence cases (Zhao, 2021). Environmental

factors is a variable category that has been largely understudied by papers examining economic factors and health outcomes. The study conducted by Atkinson, Kang, Anderson, Mills and Walton (2014) is one among many that underscore the association between environmental factors and CVD outcomes. Therefore, CO2 emission is included in the models as one of the controlling variables. Given the differences among the countries selected for our sample, these variables are controlled to isolate the specific effects of the independent variables on CVD outcomes. Furthermore, as stated in the work of Grossman (1972), health can be viewed as a function of various factors, such as lifestyle, behavior, and environmental factors. By accounting for confounding factors, we can ensure more accurate and reliable results in the regression analysis, thereby aligning with Grossman's theoretical framework.

However, there are numerous unobservable factors specific to the selected countries that could influence the relationship between CVD policies and mortality. The most significant aspects are culture and religion. SEA is a region characterized by a wide range of traditions, cultures, and religions. The religious landscape includes Buddhism, Islam, Christianity, Hinduism, and many local traditional religions, with each intertwined with cultural and familial traditions (Miner, Evans, Starr & Corichi, 2023). This diversity results in a wide array of habits, lifestyles, and dietary practices, making it challenging to control for these variables in the models. Therefore, a term α is included in the models to account for any other country-specific unobservable effects, including culture and religion.

3.2 Econometric method

This section specifies the econometric strategy used to analyze the various relationships between CVD mortality and CVD policies (GDP per capita, CHE per capita, and tobacco tax). For each of these relationships, a different variation of a log-log regression model will be utilized. The analysis will be conducted in two instances. The first instance, referred to as the "Basic model", is a regression of CVD outcome on the economic factor with the inclusion of a squared independent term to account for non-linearity, as demonstrated in Spiteri and Von Brockdorff (2019). The second instance, termed the "Extended model," builds upon the "Basic model" by incorporating the control variables listed in Table 13. The specific model used for each analysis will be provided in its corresponding section.

Both instances will be estimated using both Fixed Effects (FE) and Random Effects (RE) specifications, as applied in Spiteri and Von Brockdorff (2019). The FE specification controls for all time-invariant differences between countries in the sample, thereby eliminating the influence of unobservable omitted variables that are constant over time. However, this approach also means that individual time-invariant variables cannot be estimated in this model since the FE method differences it out by default. Only time-varying factors are included and remain in the model. Despite this limitation, the FE model remains robust as it focuses on within-country variation. Conversely, the RE specification can estimate both within-group and between-group variation, including time-invariant factors. However, it assumes that country-specific unobservable effects are uncorrelated with the independent variables, which may not be realistic in this context. Therefore, the FE specification will be considered more robust and reliable, and its results will be used for most of the analyses' interpretation. Akaike Information Criterion (AIC) and Bayesian

Information Criterion (BIC) scores will complement the FE's result to ensure the best model is selected. Nevertheless, the analysis will contain both specifications for alternative interpretation of the results. Since homoskedasticity might not hold, cluster-robust standard errors are used to account for heteroscedasticity and within-cluster correlation. This ensures that standard errors are robust to different variances of error terms and correlated observations within each country.

3.3 Potential concerns

The analysis may still encounter several issues due to the inherent characteristics of the selected variables. Specifically, the independent and dependent variables could exhibit simultaneous causality. As CVD mortality improves or deteriorates, economic development could be influenced. In a study by Suhrcke and Urban (2010), the authors identified a negative impact of CVD outcomes on economic development. Similarly, CVD deaths might influence tobacco taxation, as governments may adjust tax policies in response to public health data. Moreover, health expenditures could be adjusted based on the previous year's CVD statistics, which means that the independent variable is autocorrelated. Multicollinearity is also a possible concern, especially with the inclusion of non-linear analysis. Including a squared variant of an independent variable could lead to inflated coefficients and even affect the sign of it. However, using logarithmic transformation per Spiteri and Von Brockdorff (2019) could potentially mitigate this problem as the author based their model on the Kuznets Curve. Given these challenges, it is crucial to interpret the findings of this paper with caution, and any causal conclusions must be rigorously tested.

4 Result Analysis

4.1 Evidence for inverted U-shaped relationship between economic development and CVD mortality

The study by Spiteri and Von Brockdorff (2019), which serves as an inspiration for this thesis, examines the relationship between GDP per capita and CVD mortality rates. Utilizing a comprehensive panel analysis of 27 European countries from 2003 to 2014, the authors used log-log regression models to estimate the effect between these two variables. Their findings reveal a statistically significant inverted U-shaped correlation between GDP per capita and CVD mortality rates, which indicates that CVD mortality rates initially increase with economic growth but begin to decline once a certain level of income per capita is reached. Given the unique socio-economic, environmental conditions, lifestyle, and existing challenge of CVD in SEA, this subsection of the result section aims to explore whether Spiteri and Von Brockdorff (2019) findings are replicable in this region, particularly examining the existence of a similar inverse U-shaped relationship in the collected sample.

4.1.1 Basic model

$$\ln(CVD)_{it} = \beta_0 + \beta_1 \ln(GDP)_{it} + \beta_2 \ln(GDP^2)_{it} + \alpha_i + u_{it} \tag{1}$$

where:

$$\begin{aligned} \text{CVD}_{it} &= \text{Proportion of CVD deaths of Country } i \text{ in Year } t \\ \text{GDP}_{it} &= \text{GDP per capita of Country } i \text{ in Year } t \\ \alpha &= \text{Country-specific unobservable effect of Country } i \\ u_{it} &= \text{Random disturbance term} \end{aligned}$$

The Basic Model's (equation 1) results with both the fixed and random effect specification are shown in Table 2. The findings from both of these specifications are relatively similar in value. With a positive Log GDP per capita and a negative Log GDP per capita squared, it can be indicated that there is an inverted U-shaped relationship between economic development and CVD mortality in seven SEA countries. However, both of the coefficients are insignificant and the problem of multicollinearity between the independent variable and itself squared might impact the basic interpretation of the coefficients. Therefore this result should still be complemented by a more robust model that includes other explanatory variables to reduce omitted variable bias.

Table 2
Basic Model: Fixed and Random Effects Regression Results for GDP per capita and CVD Mortality

Explanatory Variables	**Fixed Effects**	**Random Effects**
Log GDP per capita	0.3578099	0.3807219
	(0.2718099)	(0.2656258)
Log GDP per capita squared	-0.178145	-0.196373
	(0.0158093)	(0.0153668)
Constant	-8.108882	-8.171472
	(1.153429)	(1.164068)
N	140	140
R-squared (within)	0.3847	0.3827
R-squared (between)	0.5481	0.4869
R-squared (overall)	0.1651	0.1183
F-statistic	2.22	-
	Prob > F = 0.1893	
Wald Chi-Square statistics	-	3.81
		Prob > chi2 = 0.1485

Notes: *p < 0.1; **p < 0.05; ***p < 0.01. Robust standard errors, adjusted for 7 clusters in the sample of SEA countries, are reported in parentheses.

4.1.2 Extended model

$$\begin{aligned}\ln CVD_{it} = \beta_0 &+ \beta_1 \ln GDP_{it} + \beta_2 (\ln GDP_{it})^2 + \beta_3 \ln Smoking_{it} \\ &+ \beta_4 \ln CO2_{it} + \beta_5 \ln Diabetes_{it} + \beta_6 \ln HDI_{it} \\ &+ \beta_7 \ln Hypertension_{it} + \beta_8 \ln Obesity_{it} \\ &+ \alpha_i + \varepsilon_{it}\end{aligned} \tag{2}$$

where:

$$\begin{aligned}\text{Smoking}_{it} &= \text{Prevalence of smoking in country } i \text{ in time } t \\ \text{CO2}_{it} &= \text{Annual CO2 emission per capita in country } i \text{ during year } t \\ \text{Diabetes}_{it} &= \text{Prevalence of diabetes mellitus in country } i \text{ during year } t \\ \text{HDI}_{it} &= \text{Human Development Index in country } i \text{ during year } t \\ \text{Hypertension}_{it} &= \text{Hypertension prevalence per capita in country } i \text{ during year } t \\ \text{Obesity}_{it} &= \text{Obesity prevalence per capita in country } i \text{ during year } t\end{aligned}$$

Equation 2 incorporates all the control variables outlined in the methodology section, although it does not include every variable used by Spiteri and Von Brockdorff (2019) due to limited data availability in SEA. Nevertheless, this approach remains valid as the categories of variables included are consistent with those in the original study. Table 3 contains the FE results and Table 4 the RE results analysis. Control variables are sequentially incorporated and serve several purposes in this panel regression analysis. It allows for the observation of the incremental impact each variable has on the dependent variable. Significant shifts in the coefficients upon introducing new controls may indicate sensitivity to omitted variable bias in simpler models. Additionally, this method is instrumental in detecting issues such as multicollinearity or overfitting. These are common econometric conditions where the inclusion of new variables drastically changes the coefficients and statistical significance of variables already in the model, potentially making predictors redundant or interdependent. Moreover, building the model sequentially allows for the monitoring of goodness-of-fit statistics.

As indicated by the results, there is some evidence that also points towards an inverse U-shaped relationship. This is evident by the statistically significant positive coefficients on the logarithmic GDP per capita and the significant negative coefficients on the squared term of logarithmic GDP per capita in some model specifications. In the FE specification, Model 1 shows that both coefficients for Log GDP per capita and Log GDP per capita squared are statistically significant. However, in Models 2 and 3, only the squared GDP term remains statistically significant. In all subsequent models, the coefficients for GDP per capita and its squared term are not significant. This shows how sensitive the estimated relationship is to the inclusion of different control variables. The variations in statistical significance across the models suggest overfitting, where the model fits the sample data too well at the expense of generalizability. It could also mean that there is a multicollinearity problem, where high correlations between predictor variables inflate the variance of the estimates, affecting their reliability. To address these

concerns, the FE analysis should be followed up with additional robustness checks. Specifically, the models are tested with the AIC and the BIC scores, which will help assess the goodness of fit while penalizing the complexity of the model. They help in selecting the model that best balances fit and simplicity, with lower scores indicating a better model. The result of this test is detailed in Table 5. From the scores, it can be concluded that Models 1 and 2 are the preferable choices based on AIC and BIC scores. These models have the lowest AIC and BIC values, suggesting they offer the best balance between the goodness of fit and complexity among the compared models.

The RE results presented in Table 4 provide a more definitive analysis compared to the FE results discussed previously. Specifically, Model 1 in the RE specification is highly significant at the 99% confidence interval. This is noteworthy as the outcome aligns closely with Model 1 of the FE specification and the basic model described in Equation 1. As additional control variables are introduced in the subsequent models, there is a notable increase in the coefficients of GDP per capita. This increase suggests that the coefficients in Model 1 were initially underestimated and that adding more relevant variables helps capture more accurately the impact of GDP on cardiovascular disease mortality. It is clear that Model 6 in the RE specification, where both GDP per capita and its squared term are statistically significant, is the most complete and yields the most accurate outcome. This result confirms the presence of an inverse U-shaped relationship between GDP per capita and cardiovascular disease mortality within this specification. Therefore, the null hypothesis that GDP per capita does not demonstrate a "Kuznets curve" relationship with CVD mortality is rejected. However, in choosing the RE specification, we have to assume that the RE is uncorrelated with GDP per capita across all periods, which might not be realistic in this context.

From the estimates provided by the FE and RE specification, the turning point can be calculated with Equation 3. The RE specification tells us that the GDP per capita level where the rate of CVD mortality starts to decline is around \$16,606. As of 2019, among the countries in the selected sample, only Singapore has exceeded this identified peak of economic development. This means that Singapore has already been experiencing a reduction in CVD mortality rates following economic growth. This finding is not surprising, as almost all of the countries in the sample are developing countries, and Singapore is the only country that can be classified as a developed country. Conversely, the FE specification identifies a lower peak range of about \$5,817 to \$6,919, suggesting that Thailand and Malaysia, along with Singapore, have surpassed this economic threshold. The choice between the FE or RE specification is based on the set of assumptions that we are willing to accept. The FE model is typically considered more robust because it controls for time-invariant effects and focuses on within-entity variations. However, the results from the RE model are also significant as they offer a more complete model with all control variables. Unlike fixed effects, the random-effects model considers both within-group and between-group variability. Broader variability, such as the variation in confounding variables correlating with CVD mortality, is also captured by the RE specification. Therefore, insignificant relationships could be reflected as significant in the specification, which is the reason that the FE specification yields more reliable results in this context. It is also important to note that the size of the effects might be economically insignificant in the short run, as a 1% change in

any independent variable may result in a change of less than 1% in CVD mortality rates. When compounded over a certain period, however, it could be more economically significant.

$$\text{Peak} = \exp\left(\frac{-\beta_1}{2\beta_2}\right) \tag{3}$$

In examining other control variables, interesting results emerge. Smoking prevalence and hypertension prevalence consistently exhibit coefficients that are statistically significant at a 95% confidence interval across all versions of the FE models. Notably, for every percentage point increase in smoking prevalence, there is an approximate 0.47-0.6% decrease in CVD mortality rates. This finding is unexpected, as existing literature established smoking as one of the main risk factors for CVD. Nevertheless, within this specific sample of countries, this potentially spurious relationship persists. This is evidenced by the RE model, which, although lacking the same level of statistical significance, similarly displays negative coefficients for smoking prevalence. Conversely, the prevalence of hypertension aligns more closely with the conventional understanding of CVD risk factors. In the FE model, hypertension prevalence consistently shows a positive coefficient, signifying an increase in CVD mortality rates. Specifically, for every 1% increase in hypertension prevalence, CVD mortality increases by approximately 1%. The RE model supports this relationship but with a slightly lower impact of 0.6%. Additionally, the RE model indicates that a 1% increase in obesity prevalence leads to a 2% decrease in CVD mortality, which is also counterintuitive given the well-documented role of obesity as a CVD risk factor.

Table 3

Extended Model: Fixed Effect Results for GDP per capita and CVD mortality

Variable	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
GDP per Capita	0.462906**	0.5429329*	0.5437326*	0.6670662*	0.2812966	0.3056661
	(0.1215002)	(0.2340635)	(0.2343839)	(0.2781325)	(0.1548248)	(0.2035665)
GDP per Capita Squared	-0.0266756**	-0.0307058**	-0.0307058**	-0.363128**	-0.154304	-0.0164439
	(0.0065534)	(0.0120724)	(0.010724)	(0.1384841)	(0.0985929)	(0.010984)
Smoking Prevalence per Capita	-0.6195966**	-0.5781732**	-0.5871832**	-0.4672162**	-0.5555068***	-0.5834051**
	(0.1401193)	(0.1097512)	(0.242303)	(0.1891671)	(0.1002331)	(0.109603)
CO2 Emissions per Capita	-	-0.2288786	-0.2680284	-0.2288786	0.0179394	0.0159496
	-	(0.4535757)	(0.2650354)	(0.4535757)	(0.349743)	(0.042332)
Diabetes Prevalence per Capita	-	-	0.0695835	0.1771309	0.0337352	0.0605282
	-	-	(0.1387201)	(0.1125197)	(0.1450319)	(0.2048132)
Human Development Index	-	-	-	-0.800799	-0.5981477	-0.5444171
	-	-	-	(0.8733999)	(0.5370971)	(0.4111427)
Hypertension Prevalence per Capita	-	-	-	-	1.008771**	0.9988596**
	-	-	-	-	(0.267075)	(0.2904637)
Obesity Prevalence per Capita	-	-	-	-	-	-0.035587
	-	-	-	-	-	(0.0940735)
Constant	-6.376196***	-6.846217***	-6.7692516**	-2.010081	-5.402662	-5.69929
	(0.9867614)	(1.581335)	(1.658425)	(5.173478)	(3.425607)	(2.932504)
N	140	140	140	140	140	140
R^2 (within)	0.5921	0.5989	0.6073	0.6301	0.7512	0.7525
R^2 (between)	0.7447	0.7793	0.7680	0.4059	0.2921	0.2875
R^2 (overall)	0.3662	0.3216	0.2796	0.0939	0.1194	0.1164
F-statistic	133.02	181.13	65.47	25.16	6.00	-
Prob > F	0.0000	0.0000	0.0000	0.0005	0.0025	-

Note. Standard errors in parentheses. *p < 0.1; **p < 0.05; ***p < 0.01. Robust standard errors, adjusted for 7 clusters in the sample of SEA countries, are reported in parentheses.

Table 4

Extended Model: Random Effect Results for GDP per capita and CVD mortality

Variable	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
GDP per Capita	0.4786836***	0.7559465**	0.7657407**	0.3297245	0.3467303	1.134995**
	(0.1217972)	(0.2702502)	(0.2877524)	(0.4560401)	(0.3678527)	(0.4231399)
GDP per Capita Squared	0.027844***	-0.425599	-0.441055**	-0.0238231	-0.238239	-0.0584378**
	(0.0064146)	(0.319164)	(0.1446598)	(0.208118)	(0.202818)	(0.0216265)
Smoking Prevalence per Capita	-0.5692796***	-0.3172205	-0.4491829	-0.4973385	-0.3001487	-0.5151585
	(0.173054)	(0.2498962)	(0.3192056)	(0.682359)	(0.5393247)	(0.4287603)
CO2 Emissions per Capita	-	-0.8902510	-0.1172375	-0.6623567	-0.0722748	-0.1172354*
	-	(0.5657182)	(0.363727)	(0.389793)	(0.2098584)	(0.0496992)
Diabetes Prevalence per Capita	-	-	0.1443514	0.1170086	0.104661	0.367414
	-	-	(0.128397)	(0.2375372)	(0.229483)	(0.166557)
Human Development Index	-	-	-	-0.1270175	-0.0379358	-1.127295
	-	-	-	(0.3978493)	(0.102734)	(0.6076227)
Hypertension Prevalence per Capita	-	-	-	-	-0.2912821	0.6127182**
	-	-	-	-	(0.4081658)	(0.1594113)
Obesity Prevalence per Capita	-	-	-	-	-	-2.195938***
	-	-	-	-	-	(0.318289)
Constant	-5.866425***	-8.582459***	-8.593628***	-8.027898	-8.926113	-7.272314**
	(1.156552)	(1.848888)	(1.840848)	(5.216255)	(5.437914)	(2.572113)
N	140	140	140	140	140	140
R^2 (within)	0.5897	0.5307	0.5194	0.0747	0.6070	0.1421
R^2 (between)	0.7480	0.7793	0.0419	0.6068	0.6095	0.9466
R^2 (overall)	0.3424	0.3216	0.0945	0.4862	0.4997	0.8136
Wald-Chi square	146.11	53.11	99.42	244.53	28.00	24.00
Prob > chi2	0.0000	0.0000	0.0000	0.0000	0.0025	0.0000

Note. Standard errors in parentheses. *p < 0.1; **p < 0.05; ***p < 0.01. Robust standard errors, adjusted for 7 clusters in the sample of SEA countries, are reported in parentheses.

Table 5

Akaike's Information Criterion and Bayesian Information Criterion for GDP per capita results

	N	**ll(null)**	**ll(model)**	**df**	**AIC**	**BIC**
Full Model	140	157.9159	255.6707	6	-499.3413	-481.6915
Model 1	140	157.9159	220.6815	3	-435.3631	-426.5382
Model 2	140	157.9159	221.8561	4	-435.7121	-423.9456
Model 3	140	157.9159	223.3391	5	-436.6783	-421.9701
Model 4	140	157.9159	227.537	6	-443.0739	-425.4241
Model 5	140	157.9159	255.3011	6	-498.6023	-480.9524

Note: Each numbered "Model" adds a new control variable to the test. "Model 1" adds $Smoking_{it}$. "Model 2" adds $CO2_{it}$. "Model 3" adds $Diabetes_{it}$. "Model 4" adds HDI_{it}. "Model 5" adds $Hypertension_{it}$. "Full Model" includes all of the control variables as per Equation 2

4.1.3 Robustness test

A potential limitation of our study arises from unobservable time-variant factors that collectively affect the seven ASEAN countries selected for this analysis. These countries could be simultaneously impacted by joint regional health initiatives, such as the SEAHEART initiative, which focuses on scaling up the treatment, coverage, and control of hypertension and diabetes. This initiative also targets CVD risk factors like tobacco use, unhealthy diets, and physical inactivity (World Health Organization, 2023).

Additionally, one econometric challenge in the research is the issue of reverse causality between CVD mortality and GDP per capita. Spiteri and Von Brockdorff (2019) proposed to solve this problem by considering that CVD mortality might reflect broader trends in CVD prevalence, which in turn could influence GDP per capita. Therefore, in their study, CVD prevalence was included as a control variable for robustness testing. Furthermore, Spiteri and Von Brockdorff (2019) utilized Gini coefficients in their robustness checks to control for changes in inequality and poverty. Unfortunately, due to data constraints with our selected sample, Gini coefficients are available only every five years. Therefore this variable was excluded from our analysis. Nonetheless, it is important for future research to explore the implications of income inequality, as its changes could substantially impact GDP per capita and access to healthcare, thereby influencing CVD mortality rates.

To mitigate the influence of such time-varying factors and reverse causality concerns, this paper has followed the approach suggested by Spiteri and Von Brockdorff (2019) and adjusted our model to control for these characteristics. Specifically, Equation 2 has been re-estimated by incorporating a dummy variable for 18 out of the 19 years under study, using 2019 as the baseline year. CVD prevalence will be included along with these time-fixed dummies. To maintain focus, the reported results will concentrate solely on our primary variables of interest, GDP per capita & GDP per capita squared, and GDP prevalence. Consistent with the methodology in section 4.1.2, Model 1 for the FE specification and Model 6 for the RE specification are chosen to be the most fitting for this analysis. The result of this analysis is shown in Table 6. After controlling for time-varying characteristics and including CVD prevalence that Spiteri and Von Brockdorff (2019) proposed to solve reverse causality, the results continue to show statistically significant evidence supporting the inverse U-shaped relationship between GDP per capita and CVD mortality.

Table 6
Robustness Test Model with CVD prevalence and time-fixed dummies for GDP per capita

Explanatory Variables	**Fixed Effects**	**Random Effects**
Log GDP per capita	0.5948745**	0.6597923**
	(0.1857487)	(0.2403552)
Log GDP per capita squared	-0.0351893**	-0.0351673**
	(0.0091095)	(0.0120894)
Log CVD prevalence	-0.2827282	-0.1553711
	(0.2748436)	(0.1366062)
Constant	-6.007021	1.490988
	(1.26921)	(2.565752)
N	140	140
R-squared (within)	0.6898	0.6442
R-squared (between)	0.7425	0.9681
R-squared (overall)	0.4800	0.9318
F-statistic	-	-
	Prob > F = -	
Wald Chi-Square statistics	-	-
		Prob > chi2 = -

Notes: *p < 0.1; **p < 0.05; ***p < 0.01. Robust standard errors, adjusted for 7 clusters in the sample of SEA countries, are reported in parentheses.

4.2 Relationship between CHE and CVD mortality

4.2.1 Basic Model

$$\ln(CVD)_{it} = \beta_0 + \beta_1 \ln(CHE)_{it} + \beta_2 \ln(CHE^2)_{it} + \alpha_i + u_{it} \tag{4}$$

where:

$$\text{CHE}_{it} = \text{Current health expense in US dollars of country } i \text{ in time } t$$

This section will present the empirical results of the regression model of CVD mortality on CHE as an extension of Spiteri and Von Brockdorff (2019) results. Consistent with the approach in Section 4.1, the analysis starts with the examination of Equation 4, referred to as the "Basic model."

The results are shown in Table 7 with the findings from the Random and Fixed Effects specifications reported in columns 1 and 2 respectively. The findings of both the FE and RE specifications are very similar, with both of the specifications indicating that the coefficient of the natural logarithm of CHE is around 0.31 and statistically significant at 95% confidence interval. However, the coefficient of Log CHE squared is only significant in the RE specification. This may

suggest that we have to assume that all country-specific unobservable effects are not correlated with the independent variable across all panels. To solidify the existence of an inverse U-shaped relationship between CHE per capita and CVD mortality per capita, a more robust model is needed.

Table 7
Basic Model: Fixed and Random Effects Regression Results for CHE per capita and CVD Mortality

Explanatory Variables	Fixed Effects	Random Effects
Log CHE per capita	0.3056887**	0.3130268**
	(0.1167549)	(0.1153946)
Log CHE per capita squared	-0.0248351*	-0.0260654**
	(0.0116683)	(0.0114604)
Constant	-7.254842***	-7.259578***
	(0.2817259)	(0.3261958)
N	140	140
R-squared (within)	0.5310	0.5300
R-squared (between)	0.3874	0.3244
R-squared (overall)	0.0619	0.0388
F-statistic	6.29	-
	Prob > F = 0.0336	
Wald Chi-Square statistics	-	11.40
		Prob > chi2 = 0.0034

Notes: *p < 0.1; **p < 0.05; ***p < 0.01. Robust standard errors, adjusted for 7 clusters in the sample of SEA countries, are reported in parentheses.

4.2.2 Extended Model

The Basic Model is now extended to include different categories of potential confounders similar to Equation 2, staying consistent with the methodology of Spiteri and Von Brockdorff (2019). The "Extended Model" uses the same set of control variables as those used in the previous sections. We can use the same control variables because CHE per capita is another economic indicator with similar confounding factors as GDP per capita. Utilizing learnings from the econometric problems that this regression might face outlined in section 4.1.3, this model includes time-fixed effects to mitigate time-varying unobservable influences and Log CVD Prevalence to address potential issues of reverse causality. The Extended Model is specified in Equation 5.

$$\begin{aligned} \ln CVD_{it} = \beta_0 &+ \beta_1 \ln CHE_{it} + \beta_2 (\ln CHE_{it})^2 + \beta_3 \ln Smoking_{it} \\ &+ \beta_4 \ln CO2_{it} + \beta_5 \ln Diabetes_{it} + \beta_6 \ln HDI_{it} \\ &+ \beta_7 \ln Hypertension_{it} + \beta_8 \ln Obesity_{it} + \beta_9 \ln Prevalence_{it} \\ &+ Dummies + \alpha_i + \varepsilon_{it} \end{aligned} \tag{5}$$

where:

$$\text{Dummies}_{it} = \text{Time-fixed effects dummy variables.}$$
$$\text{Prevalence}_{it} = \text{The proportion of people in country } i \text{ in year } t \text{ who are a case of CVD}$$

The FE and RE results are shown in Table 8. The results in this section do not include the incremental addition of control variables. The problem faced by the GDP per capita analysis - such as overfitting and biases that significantly alter the coefficients or their statistical significance – is not present in this section. Therefore, for brevity, only the fullest model is reported and the time-fixed dummies are visually excluded from Table 8. As observed, the results continue to demonstrate a non-linear relationship between CHE and CVD mortality in both specifications. Similar to the dynamics between GDP per capita and CVD mortality, there is evidence for an inverse U-shaped relationship or a "Kuznets curve" between CHE and CVD mortality. This relationship is evidenced by the statistical significance of the squared term of Log CHE per capita within a 95% confidence interval across both model specifications. However, the coefficient of the Log CHE per capita requires particular attention. It is substantially different from the results of the Extended Model's RE coefficients as well as from those observed in both specifications of the Basic Model. Such a shift in the coefficient's value may indicate that not controlling for confounding factors and time-variant variables leads to a downward bias in the variable. Nevertheless, the hypothesis that economic factors such as CHE per capita do not demonstrate a "Kuznets curve" or an inverse U-shaped relationship with CVD mortality is rejected.

Using Equation 3, the FE specification indicates that the turning point for CHE per capita is around $158. As of 2019, Thailand, Malaysia, Singapore, and Vietnam have surpassed this point, indicating that their health spending is in a phase where more budget allocated to healthcare correlates with the reduction of CVD mortality rates. The RE's coefficient, however, suggests that the coefficient is upwardly biased without the control variables. According to the RE specification, the turning point is significantly higher- identified at $761.3 - a threshold only surpassed by Singapore. This result should be interpreted with caution, as the RE specification considers both within and between-group variation and its assumptions are difficult to justify. Given that Singapore has exhibited an average health expenditure per capita of approximately $1575 over the 19 years covered by our dataset, there is a plausible risk that the RE model may overestimate the impact.

It is also important to investigate the effect of other explanatory variables. Obesity prevalence is notably significant at a 95% confidence interval in both specifications, with a 1% increase in the proportion of obese people associated with a 0.14 - 0.19% decrease in mortality rates. Similar to Smoking prevalence in the GDP per capita analysis, this is unusual as obesity is another established risk factor for CVD. The prevalence of CVD increases CVD mortality by 0.45-0.51% with a 1% increase. Interestingly, the Human Development Index, Smoking, and Diabetes prevalence only have a statistically significant effect in the random effect specification, whereas in the fixed effect specification, they are highly insignificant. However, the interpretation of the random effects specification should proceed with caution, as detailed in the previous sections.

Table 8
Extended Model: FE and RE Results for CHE per capita and CVD mortality

Variable	Fixed Effect	Random Effect
CHE per Capita	0.5845562***	0.238863***
	(0.1287187)	(0.1403908)
CHE per Capita Squared	-0.0577348***	-0.0180404**
	(0.0126903)	(0.0258236)
Smoking Prevalence per Capita	-0.3815958	-0.3619257***
	(0.0761235)	(0.1356721)
CO2 Emissions per Capita	-0.0512713	-0.0464244
	(0.3433114)	(0.037653)
Diabetes Prevalence per Capita	-0.0452345	-0.1615048***
	(0.058157)	(0.1469136)
Human Development Index	-0.7832025	-1.71381***
	(0.7017738)	(0.434682)
Hypertension Prevalence per Capita	-0.08104	-0.88844***
	(0.2987768)	(0.2987768)
Obesity Prevalence per Capita	-0.1407694**	-0.1932912***
	(0.0440454)	(0.1145096)
CVD Prevalence per Capita	0.5199447**	0.4515485**
	(0.1503714)	(0.1558099)
Constant	-3.0988525	1.55141
	(4.7563552)	(2.878099)
N	140	140
R^2 (within)	0.5300	0.7307
R^2 (between)	0.3244	0.9746
R^2 (overall)	0.0388	0.9648
F-statistic	11.40	77.38
Prob > F	0.0034	0.0000

Note. Standard errors in parentheses. *p < 0.1; **p < 0.05; ***p < 0.01. Robust standard errors, adjusted for 7 clusters in the sample of SEA countries, are reported in parentheses.

4.3 Relationship between excise tobacco tax and CVD mortality

4.3.1 Basic Model

This section will present the empirical results of the regression model of CVD mortality on Excise Tobacco Tax as an extension of Spiteri and Von Brockdorff (2019) results. The methodology employed parallels with that of Section 4.2. However, data for Excise Tobacco Tax is only available bi-annually. Therefore, estimates for Excise Tobacco Tax have been interpolated, taking the mean of the year before and after, to provide a continuous dataset. The data range is

also shorter, covering only 2008 to 2018. Nevertheless, the sample size is still large enough to gather economically significant results.

This analytical process begins with an examination of Equation 6, named the "Basic model," staying consistent with the methodologies in Sections 4.1 and 4.2. The Basic Model's results from both the FE and RE specification are shown in Table 9. Contrary to expectations of an inverted U-shaped relationship, the "Basic Model" findings indicate a U-shaped relationship. This is evidenced by negative coefficients for Tobacco Tax and positive coefficients for its squared term, with all coefficients being statistically significant at a 95% confidence interval. To confirm that indeed it is a U-shaped relationship, the following section will include all possible confounding factors to have the least biased result possible.

$$\ln(CVD)_{it} = \beta_0 + \beta_1 \ln(Tax)_{it} + \beta_2 \ln(Tax^2)_{it} + \alpha_i + u_{it} \tag{6}$$

where:

Tax_{it} = Excise tax of tobacco in proportion of price of country i in time t

Table 9
Basic Model: Fixed and Random Effects Regression Results for Excise Tobacco Tax and CVD Mortality

Explanatory Variables	Fixed Effects	Random Effects
Log Tobacco Tax	-0.431205***	-0.326202**
	(0.127826)	(0.185553)
Log Tobacco Tax squared	0.0142891**	0.0108684**
	(0.0032151)	(0.0050615)
Constant	-6.413721***	-6.406591***
	(0.057301)	(1.025041)
N	140	140
R-squared (within)	0.0942	0.0942
R-squared (between)	0.3123	0.3114
R-squared (overall)	0.2428	0.2421
F-statistic	58.84	-
	Prob > F = 0.0001	
Wald Chi-Square statistics	-	6.31
		Prob > chi2 = 0.0426

Notes: *p < 0.1; **p < 0.05; ***p < 0.01. Robust standard errors, adjusted for 7 clusters in the sample of SEA countries, are reported in parentheses.

4.3.2 Extended Model

$$\begin{aligned}\ln CVD_{it} = \beta_0 &+ \beta_1 \ln Tax_{it} + \beta_2 (\ln Tax_{it})^2 + \beta_3 \ln Hypertension_{it} \\ &+ \beta_4 \ln Diabetes_{it} + \beta_5 \ln Obesity_{it} + \beta_6 \ln HDI_{it} \\ &+ \beta_7 \ln Prevalence_{it} + \beta_8 \ln CO2_{it} + \beta_9 \ln Smoking_{it} \\ &+ Dummies + \alpha_i + \varepsilon_{it}\end{aligned} \tag{7}$$

The Basic Model is now extended to include different categories of potential confounders to stay consistent with the methodology of Spiteri and Von Brockdorff (2019) and the previous sections. The reason that the same control variables are implemented is that the Excise Tobacco Tax serves as an economic indicator, much like GDP per capita, and is likely influenced by similar confounding factors. The Extended Model of this analysis is specified in Equation 7.

Table 10 contains the FE results and Table 11 the RE results analysis, sequentially incorporating various control variables. Similar to 4.1.2, sequentially adding the control variables in this panel regression analysis allows us to observe the incremental impact of each variable on the dependent variable. Furthermore, common econometric issues can be detected. Such issues are potential omitted variable bias, multicollinearity, or overfitting issues, and identifying redundancy or interdependence among independent variables. The different model versions and specifications show no strong evidence for a U-shaped relationship between Excise Tobacco Tax and CVD mortality. While Models 1 to 3 in both FE and RE specifications indicate statistically significant coefficients for the Log of Excise Tobacco Tax, the squared term of this variable is only significant in Model 1. The AIC and BIC test, presented in Table 12 also suggest that Model 1 is the best fit. If the evidence for a U-shaped relationship is only present in the simplest model, then the claim of such a relationship is not well-substantiated. The simplest model is likely to suffer from omitted variable bias and the observed U-shaped pattern in the simplest model may be spurious. As more control variables are added to the model, the evidence for a U-shaped relationship diminishes. Therefore, the hypothesis that Excise Tobacco Tax does not demonstrate an inverse U-shaped relationship or "Kuznets curve" is not rejected.

The analysis primarily supports a linear relationship between Excise Tobacco Tax and CVD mortality rates. Specifically, the FE specification indicates a 0.62% to 0.69% decrease in CVD mortality for every 1% increase in Excise Tobacco Tax, while the RE specification suggests a 0.55% to 0.68% decrease. However, several econometric issues hinder the interpretation of these variables, and any inferences made must be further tested. The data had to be interpolated for missing years, potentially distorting the relationship, especially for the squared term. This is because the interpolation smooths out the data to introduce artificial trends, leading to underestimation of the true data variability and can affect the magnitude of the relationship. Therefore, the informative power of the results is diminished. Furthermore, the increasing p-values as more control variables are added suggest multicollinearity and overfitting, inflating standard errors and obscuring the true relationship between the variables. Since the range of the results is numerically close to each other, it does not matter which specification is preferred, though FE in general is more robust.

Table 10

Extended Model: Fixed Effect Results for Excise Tobacco Tax and CVD mortality

Variable	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7
Excise Tobacco Tax	-0.0692583***	-0.0362202**	-0.0622574**	-0.0736277	-0.0411918	-0.0524791	-0.0181804
	(0.0133647)	(0.0185553)	(0.0253924)	(0.0771615)	(0.522331)	(0.483087)	(0.0577675)
Excise Tobacco Tax Squared	0.0111442**	0.0108684**	0.009071	0.0109234	0.0474551	0.0924548	0.0021654
	(0.0026861)	(0.0050615)	(0.0063823)	(0.0145847)	(0.114382)	(0.0160249)	(0.0160263)
Hypertension Prevalence per Capita	0.5338271**	0.4762418	0.6370889	0.5914945	0.7460146	0.6478962	0.6282441
	(0.1935622)	(0.1935622)	(0.4457825)	(0.6374573)	(0.6579425)	(0.6559363)	(0.554377)
Diabetes Prevalence per Capita	-	0.0268289	0.0228019	0.028327	-0.03891	-0.020891	0.123092
	-	(0.2310679)	(0.2249561)	(0.2467912)	(0.2487654)	(0.2435743)	(0.2208599)
Obesity Prevalence per Capita	-	-	-0.1589478	-0.1542859	-0.1665959	-0.1410506	-0.1180618
	-	-	(0.058249)	(0.052296)	(0.504199)	(0.0381818)	(0.0565915)
Human Development Index	-	-	-	0.1238734	0.2476869	0.5277126	0.9499088**
	-	-	-	(0.7024992)	(0.3871984)	(0.3387909)	(0.2071717)
CVD Prevalence per Capita	-	-	-	-	-	0.2916611	0.3027225
	-	-	-	-	-	(0.1577271)	(0.1702649)
CO2 Emissions per Capita	-	-	-	-	-	-0.0156246	0.0041948
	-	-	-	-	-	(0.0175422)	(0.0305118)
Smoking Prevalence per Capita	-	-	-	-	-	-	-0.3835981
	-	-	-	-	-	-	(0.3194648)
Constant	-8.081455***	-7.801395***	-8.663039***	-9.28199***	-9.694159***	-11.38865***	-12.84744***
	(0.6727474)	(2.29025)	(2.150016)	(2.873869)	(1.9893)	(1.631771)	(2.412485)
N	140	140	140	140	140	140	140
R^2 (within)	0.7491	0.7494	0.7914	0.7917	0.8166	0.8201	0.8289
R^2 (between)	0.0066	0.0416	0.5158	0.3708	0.0466	0.0006	0.2970
R^2 (overall)	0.0002	0.0139	0.5148	0.3763	0.0589	0.0038	0.2613
F-statistic	6.6	6.6	-	6.6	7.6	7.6	7.6
Prob > F	0.002	0.014	-	0.018	0.003	0.000	-

Note. Standard errors in parentheses. *p $<$ 0.1; **p $<$ 0.05; ***p $<$ 0.01.Robust standard errors, adjusted for 7 clusters in the sample of SEA countries, are reported in parentheses.

Table 11

Extended Model: Random Effect Results for Excise Tobacco Tax and CVD mortality

Variable	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7
Excise Tobacco Tax	-0.0682025***	-0.0615269**	-0.0559596**	-0.1671026	-0.0411918	-0.0524791	-0.0181804
	(0.0159293)	(0.0237823)	(0.0237996)	(0.2059994)	(0.522331)	(0.483087)	(0.0577675)
Excise Tobacco Tax Squared	0.0103976***	0.077216	0.066396	-0.0049837	0.0474551	0.0924548	0.0021654
	(0.0043533)	(0.0062633)	(0.059079)	(0.0362518)	(0.114382)	(0.0160249)	(0.0160263)
Hypertension Prevalence per Capita	0.4907254**	0.6706248	0.7952919*	0.8527101	0.7460146	0.6478962	0.6282441
	(0.2008632)	(0.3996364)	(0.3992496)	(0.1465225)	(0.6579425)	(0.6559363)	(0.554377)
Diabetes Prevalence per Capita	-	-0.9992185	-0.0455284	-0.010799	-0.03891	-0.020891	0.123092
	-	(0.1992415)	(0.2119281)	(0.115175)	(0.2487654)	(0.2435743)	(0.2208599)
Obesity Prevalence per Capita	-	-	-0.183603***	-0.2045035	-0.1665959	-0.1410506**	-0.1180618**
	-	-	(0.0474649)	(0.058918)	(0.504199)	(0.0381818)	(0.0565915)
Human Development Index	-	-	-	-1.766808	0.2476869	0.5277126	0.9499088**
	-	-	-	(0.2992024)	(0.3871984)	(0.3387909)	(0.2071717)
CVD Prevalence per Capita	-	-	-	-	-	0.2916611	0.3027225
	-	-	-	-	-	(0.1577271)	(0.1702649)
CO2 Emissions per Capita	-	-	-	-	-	-0.0156246	0.0041948
	-	-	-	-	-	(0.0175422)	(0.0305118)
Smoking Prevalence per Capita	-	-	-	-	-	-	-0.3835981
	-	-	-	-	-	-	(0.3194648)
Constant	-7.924507***	-8.861222***	-9.458628***	1.477232	-9.694159***	-11.38865***	-12.84744***
	(0.7734566)	(2.011772)	(2.0027705)	(2.327768)	(1.9893)	(1.631771)	(2.412485)
N	140	140	140	140	140	140	140
R^2 (within)	0.7482	0.7400	0.7882	0.3566	0.8166	0.8201	0.8289
R^2 (between)	0.0046	0.0686	0.6539	0.9761	0.0466	0.0006	0.2970
R^2 (overall)	0.0000	0.0831	0.6529	0.9536	0.0589	0.0038	0.2613
F-statistic	-	-	-	-	-	7.6	-
Prob > F	-	-	-	-	-	0.000	-

Note. Standard errors in parentheses. *p < 0.1; **p < 0.05; ***p < 0.01. Robust standard errors, adjusted for 7 clusters in the sample of SEA countries, are reported in parentheses.

Table 12

Akaike's Information Criterion and Bayesian Information Criterion for Excise Tobacco Tax Models

	N	**ll(null)**	**ll(model)**	**df**	**AIC**	**BIC**
Full Model	77	139.2079	207.1846	7	-400.3693	-383.9627
Model 1	77	139.2079	192.44	6	-372.8801	-358.8173
Model 2	77	139.2079	192.4915	6	-372.9829	-358.9201
Model 3	77	139.2079	199.55	6	-387.1	-373.0371
Model 4	77	139.2079	199.6049	6	-387.2098	-373.1469
Model 5	77	139.2079	204.511	7	-395.022	-378.6154
Model 6	77	139.2079	205.2591	7	-396.5182	-380.1116

Note: Each numbered "Model" adds a new control variable to the test. "Model 1" adds $Hypertension_{it}$. "Model 2" adds $Diabetes_{it}$. "Model 3" adds $Obesity_{it}$. "Model 4" adds HDI_{it}. "Model 5" adds $CO2_{it}$. "Full Model" includes all of the control variables as per Equation 2.

4.4 Theoretical model: Mechanisms

In Spiteri and Von Brockdorff (2019), the authors developed a theoretical model to explain the existence of an inverted U-shaped relationship between economic development and cardiovascular disease (CVD) mortality. The model setup involves a representative agent whose utility increases with both consumption (C) and health outcomes (H). H are influenced positively by healthcare investment (Z) and negatively by spending on "unhealthy" items (vC). Z is modeled as a Cobb-Douglas function of the agent's income (Y) and expenditure on healthcare (E), showing that higher incomes allow access to better healthcare technologies. Compiling the above, the agent has a fixed income (Y) that must be allocated between consumption (C) and healthcare expenditure (E), with good health also influencing the agent's income. The agent maximizes utility by optimally allocating Y between C and E, specifically the following optimization problem taken from Spiteri and Von Brockdorff (2019)'s paper:

$$\begin{aligned} \text{Maximize: } & U = C(1-\nu) + Y^{\alpha}E^{\beta} \\ \text{Subject to: } & Y + Y^{\alpha}E^{\beta} - \nu C \geq C + E \end{aligned} \tag{8}$$

where:

$$\alpha, \beta = \text{Returns to health outcomes from investments in healthcare}$$

This theoretical model has two possible scenarios, where the relationship could be either concave or convex. A concave relationship is where $\alpha + \beta < 1$ in Equation 8 indicates decreasing returns from healthcare investments. In this scenario, as income or economic factors increase, the marginal gains in health outcomes from additional healthcare spending diminish. Therefore, the agent in the model diverts their spending toward other consumptions rather than health expenditures for greater utility gain, which deteriorates the individual's health. The intuition, when the context expands to the scale of a country, is that the healthcare-related investment and technology resources are not being efficiently allocated, making them yield incompetent outcomes. These resources could have been allocated elsewhere, such as the general infrastructure or education, which could improve quality of life in the long term. This paper identified preliminary evidence for this relationship involving Excise Tobacco Tax, although these findings were not robust. More importantly, however, our empirical analysis observed a convex relationship between GDP per capita & CHE and CVD mortality. This relationship, mathematically expressed in Equation 8 as $\alpha + \beta > 1$, suggests increasing returns to scale from healthcare investments. As income increases in this scenario, health outcomes will initially worsen before improving. When we expand this model from maximizing the utility of a representative agent to the collective allocation of an entire country, this theoretical model explains the empirical findings in this thesis. When developing countries start to develop, income inequality widens, and disparity in healthcare access could grow. If healthcare services and insurance are more expensive due to new treatments, technologies, and infrastructure, it could mean that segments with lower incomes cannot access them. This could initially lead to worse health outcomes in that country. As economic factors improve, governments' healthcare investments become progressively more effective. More efforts are put into preventative care and campaigns, creating a healthier society, and incurring less

expensive treatment in the future. The income disparity narrows, as marginalized groups could also access better healthcare. This leads to higher health outcomes, as higher incomes or economic factors enable access to advanced health technologies, encouraging the agent to allocate more resources towards healthcare expenditure. The Spiteri and Von Brockdorff (2019) paper, though did not explicitly explain the intuition, included the Gini coefficient to account for income inequality. This aligns with the explanation of the theoretical model above.

5 Discussion and Conclusion

This thesis addresses the research question: "What is the relationship between economic factors and CVD mortality across seven selected SEA countries?" Building upon the foundational empirical work of Spiteri and Von Brockdorff (2019) and the theoretical model by Kuznets (1995), this paper explores whether the hypothesis that GDP per capita, CHE per capita, and Excise Tobacco Tax all exhibit an inverse U-shaped relationship, or "Kuznets curve" with CVD mortality is true. This hypothesis aligns with the broader economic literature on the "Kuznets Curve" across various health contexts, which suggests that while economic development initially worsens health outcomes up to a certain threshold, it improves them beyond this point. The economic factors analyzed in this paper include GDP per capita and CHE, with data spanning from 2000 to 2019, and Excise Tobacco Tax data available from 2008 to 2018, interpolated biennially to fill gaps. By extending the findings of Spiteri and Von Brockdorff (2019) from a European context to SEA, this study not only tests the replicability of these relationships in a different geographical context but also understands how such dynamics play out in developing economies with unique socio-economic landscapes. Econometrically, the relationship between the economic factors and CVD mortality was modeled using a log-log regression approach, consistent with the methodologies applied by Spiteri and Von Brockdorff (2019). This method involved the use of both RE and FE specifications. To allow for non-linearity in the relationship, squared terms of the independent variables were included. The models incorporated a range of control variables that account for socio-economic factors, lifestyle choices, CO2 emissions, and CVD risk factors and prevalence, alongside country-specific unobservable effects and time-fixed dummies.

The analysis identified a statistically significant inverse U-shaped relationship between GDP per capita and CVD mortality, consistent across both specified models even after adjusting for time-fixed effects and controlling for CVD prevalence to reduce endogeneity bias. The same relationship is also statistically significant between CHE and CVD mortality. This result rejects the null hypotheses set out at the beginning of this paper, which demonstrates that both economic growth and healthcare spending do not exhibit the inverse U-shaped relationship with CVD mortality in the SEA, and proves the existence of the Kuznets Curve. However, the hypothesis concerning Excise Tobacco Tax did not follow this pattern. The evidence suggests either a U-shaped or more likely a linear relationship between Excise Tobacco Tax and CVD mortality. The null hypothesis of Excise Tobacco Tax does not demonstrate an inverse U-shaped relationship and is thereby not rejected. This paper further confirms the empirical results through a theoretical model that examines the agent's allocation between consumption and health expenditures. It supports the claim that as economic conditions improve, access to advanced health technologies becomes more feasible, thereby encouraging agents to allocate

increased resources toward healthcare expenditures.

Although the results are not as robust as those found in Spiteri and Von Brockdorff (2019) due to various econometric concerns, the result has proved that countries like Thailand, Singapore, and Malaysia have reached a phase where greater economic growth, or increase in GDP, leads to improved CVD outcomes. Similarly, our analysis indicates that less than half of the countries in the selected sample have not yet surpassed the point where increased public health spending begins to lower CVD mortality rates. Countries like Thailand, Singapore, Malaysia, and Vietnam, have exceeded this economic threshold. Therefore, countries that are still below the GDP and CHE threshold must prioritize policies that mitigate CVD risk factors during this phase. In the short term, when economies start to develop, governments should enhance their resource allocation towards preventive measures, early detection, and effective treatment of CVD. This would mitigate the prevalence and mortality of CVD until the country hit the GDP and CHE turning point. Addressing risk factors such as smoking, obesity, diabetes, and hypertension, as well as reducing CO2 emissions, is essential to lowering the prevalence of CVD during periods of increased mortality. Moreover, this study underscores the efficacy of economic disincentives for health risk behaviors, highlighting how Excise Tobacco Tax has successfully reduced CVD mortality rates within the study's sample. A cooperative approach by a supranational entity such as ASEAN, can amplify these efforts. As mentioned before, a good step in the right direction is the SEAHEART initiative launched in 2023, which targets major CVD risk factors (World Health Organization, 2023). Building on this momentum, it is essential to strengthen partnerships with international organizations like the World Health Organization to initiate more joint efforts across ASEAN. These collaborations could assist countries in the same region but were excluded from this study. Such countries are Myanmar and Cambodia, which lack operational units for non-communicable diseases and formulate specific guidelines for managing CVDs.

Researchers could enhance this study by including additional confounding variables like Gini coefficients, sports expenditure, average exercise time, nutrition, and genetic data, which were omitted due to data constraints. Applying the Instrumental Variable method, such as Two-Stage Least Squares with variables like foreign investments or international health aid, would help confirm the findings concluded in this paper. Expanding the dataset to include all SEA countries would allow for a more thorough analysis. Future studies should explore various economic factors and their broader health impacts in SEA, utilizing similar methodologies. Additionally, building on the analysis of Excise Tobacco Tax, further research could extend to examine the effects of taxes on other health-related risk factors such as alcohol and sugar. Further research could also explore whether a Kuznets curve exists for conditions like low LDL cholesterol and Hypercholesterolemia, thereby enriching the current literature.

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Appendix

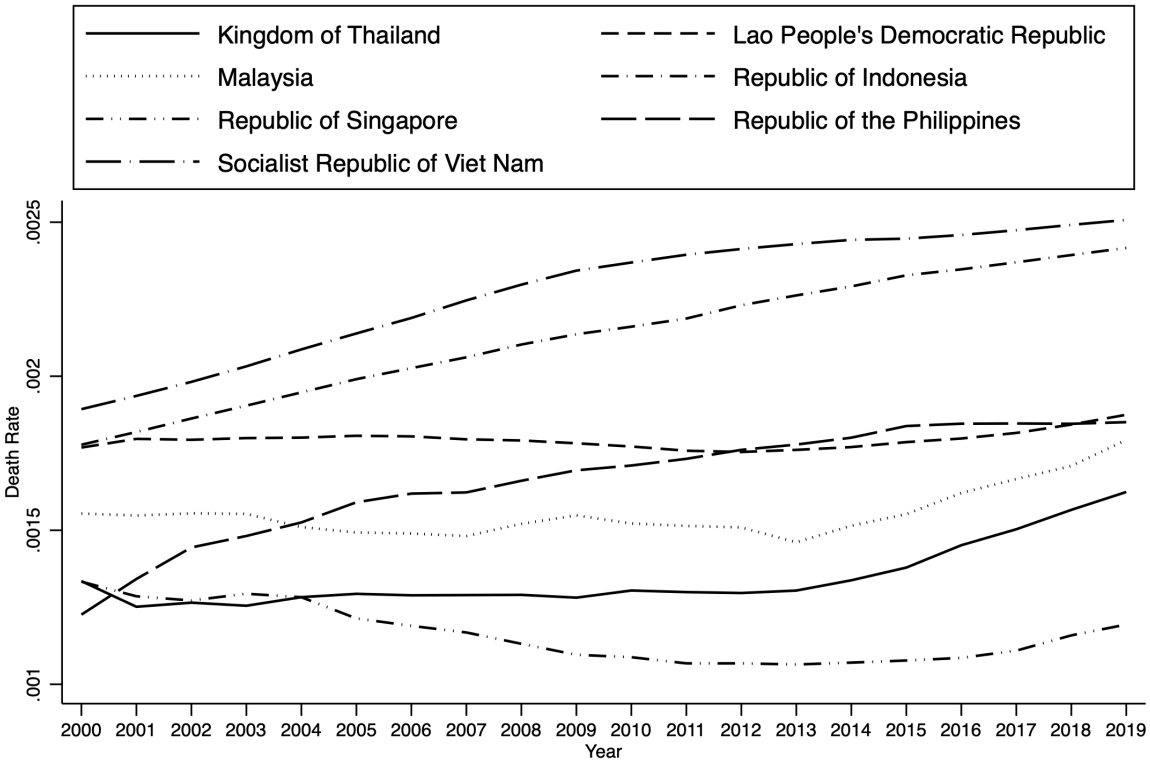

Figure 1
Rate of Death by CVD from 2000 to 2019

Table 13
Variable Overview: Lists, Descriptions and Sources

Variable List	Description	Source
Deaths per capita	Proportion of CVD deaths in a country per capita occurring in a country during a certain year.	(Global Burden of Disease Collaborative Network, 2020)
GDP per capita	GDP per capita of a country during a certain year.	(The Global Health Observatory, 2024b)
Current Health Expense	Current health expense (in US dollars) of a country during a certain year.	(The Global Health Observatory, 2024a)
Tobacco tax	Excise tax of tobacco in proportion of price.	(The Global Health Observatory, 2024c)
Prevalence per capita	The proportion of people in a country who are a case of cardiovascular disease.	(Global Burden of Disease Collaborative Network, 2020)
Obesity prevalence per capita	The proportion of people in a country who have a BMI that is larger or equal to 30kg/m^2.	(Phelps et al., 2024)
Smoking prevalence	The proportion aged 15 years and older that smoke tobacco daily. This rate is age-standardized.	(Institute of Health Metrics and Evaluation, 2022)
Human Development Index	The Human Development Index (HDI) is a summary measure of average achievement in key dimensions of human development: a long and healthy life, being knowledgeable and having a decent standard of living. The HDI is the geometric mean of normalized indices for each of the three dimensions. (0-100, more is better).	(United Nations, 2024)
Annual CO2 emission per capita	Annual CO2 emission tonnes per capita of each country.	(Friedlingstein et al., 2023)
Diabetes prevalence per capita	Prevalence of diabetes mellitus in a country during a certain year.	(Global Burden of Disease Collaborative Network, 2020)
Hypertension prevalence per capita	Prevalence of hypertension (defined as having systolic blood pressure $\geq$ 140 mmHg, diastolic blood pressure $\geq$ 90 mmHg, or taking medication for hypertension) among adults aged 30-79.	(The Global Health Observatory, 2024b)
Year indicator	Year (where t = 2000, 2001, ..., 2019).	
Country indicator	Country (where i = 1, 2, ..., 7).	
Fixed effects	Country specific unobservable effect.	