

ASSOCIATION OF GDP, NATIONAL HEALTHCARE EXPENDITURE AND
PARTICIPATION IN NATIONAL CANCER SCREENING PROGRAMMES
WITH MORTALITY FROM CANCER AND CARDIOVASCULAR
DISEASES IN THE EU COUNTRIES

by

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Dedication

To my beloved husband and my beloved son, the most important persons behind this achievement, the one who stood beside me through every challenge and the one who reminds me why every challenge mattered.

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I am also grateful to my family for their unwavering support, understanding and encouragement. Without their love and support, this achievement would not be possible.

ABSTRACT

ASSOCIATION OF GDP, NATIONAL HEALTHCARE EXPENDITURE AND PARTICIPATION IN NATIONAL CANCER SCREENING PROGRAMMES WITH MORTALITY FROM CANCER AND CARDIOVASCULAR DISEASES IN THE EU COUNTRIES

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There is complex association of GDP, national healthcare expenditure and participation in national cancer screening programmes with mortality from cancer and cardiovascular diseases. The focus of this mix-method (quantitative and qualitative) research based on

relevant open-source secondary data, is a comprehensive study on the association of GDP, national healthcare expenditure and participation in national cancer screening programmes with mortality from cancer and cardiovascular diseases in the 27 EU countries. Some of the key findings indicate a strong collective significant effect of GDP and participation in colorectal cancer screening test to total colorectal cancer mortality among the EU countries; a moderate collective significant effect of national healthcare expenditure and participation in cervical cancer screening test to total cervical cancer mortality among the EU countries; a moderate collective significant effect national healthcare expenditure and participation in colorectal cancer screening test to total colorectal cancer mortality among the EU countries. Also, valuable research-based business-related recommendations for healthcare industry were provided in terms of early detection technology, wearables technology, tobacco cessation, obesity management, commercial partnerships, partnerships with employee resource groups, high-performance computing, and increased AI-driven solutions. Future studies should address these limitations by incorporating multilevel, longitudinal datasets and adjusting for confounding variables to clarify the relationship between screening participation and breast cancer mortality.

Keywords: economy, public health, prevention, Europe, business

TABLE OF CONTENTS

List of Tables.....	x
List of Figures.....	xii
CHAPTER I: INTRODUCTION.....	136
1.1	
Introduction.....	156
1.1.1 The role of cancer screening programmes.....	17
1.1.2 Breast cancer screening.....	20
1.1.3 Cervical cancer screening.....	22
1.1.4 Colorectal cancer screening.....	24
1.1.5 Cardiovascular diseases.....	27
1.2 Research Problem.....	30
1.3 Purpose of Research.....	30
1.4 Significance of the Study.....	31
1.5 Research Objectives.....	31
CHAPTER II: REVIEW OF LITERATURE.....	32
2.1 Review of Literature.....	32
2.2 Summary.....	39
CHAPTER III: METHODOLOGY.....	40
3.1 Overview of the Research Problem.....	390
3.2 Research Questions.....	390
3.3 Research Design.....	412
3.4 Population and Sample.....	412
3.5 Instrumentation.....	412
3.6 Data Collection Procedures.....	413
3.7 Data Analysis.....	43
3.8 Research Design Limitations.....	43
3.9 Conclusion.....	43
CHAPTER IV: RESULTS AND DISCUSSION.....	44
4.1 Normality of distribution tests.....	44

4.2 Participation in breast cancer screening test and Breast cancer mortality.....	57
4.3 Participation in cervical cancer screening test and Cervical cancer mortality.....	1202
4.4 Participation in colorectal cancer screening test and Colorectal cancer mortality.....	65
4.5 GDP and Participation in breast cancer screening test.....	67
4.6 GDP and Participation in cervical cancer screening test.....	70
4.7 GDP and Participation in colorectal cancer screening test.....	72
4.8 GDP and Cardiovascular disease mortality.....	75
4.9 GDP and Breast cancer mortality.....	78
4.10 GDP and Cervical cancer mortality.....	81
4.11 GDP and Colorectal cancer mortality.....	84
4.12 Healthcare expenditure and Cardiovascular diseases mortality.....	86
4.13 Healthcare expenditure and Breast cancer mortality.....	88
4.14 Healthcare expenditure and Cervical cancer mortality.....	91
4.15 Healthcare expenditure and Colorectal cancer mortality.....	94
4.16 Multiple regression analysis of the effect of GDP and Participation in breast cancer screening test on Breast cancer mortality.....	97
4.17 Multiple regression analysis of the effect of GDP and Participation in cervical cancer screening test on Cervical cancer mortality.....	100
4.18 Multiple regression analysis of the effect of GDP and Participation in colorectal cancer screening test on Colorectal cancer mortality.....	102
4.18.1 Comparative statistical findings.....	106
4.19 Multiple regression analysis of the effect of Healthcare expenditure and Participation in breast cancer screening test on Breast cancer mortality.....	109
4.20 Multiple regression analysis of the effect of Healthcare expenditure and Participation in cervical cancer screening test on Cervical cancer mortality.....	112
4.21 Multiple regression analysis of the effect of Healthcare expenditure and Participation in colorectal cancer screening test on Colorectal cancer mortality.....	115
4.21.1 Comparative statistical findings.....	119
4.22 Business-related solutions and recommendations for the healthcare industry.....	121
4.23 Business-related recommendations for healthcare industry in cancer prevention.....	121

4.24 Business-related recommendations for healthcare industry in cardiovascular diseases prevention and treatment.....	128
4.25 Summary of Findings.....	133

CHAPTER V: CONCLUSION, IMPLICATIONS,

AND RECOMMENDATIONS.....	134
--------------------------	-----

REFERENCES	136
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LIST OF TABLES

Table 1 Dataset of variables for the EU countries (author's creation by open-source secondary data gathered from Eurostat, WHO, OECD and national health agencies).....	42
Table 2 Normality of distribution test: Shapiro-Wilk test for the variable Breast cancer mortality.....	44
Table 3 Normality of distribution test: Shapiro-Wilk test for the variable Cervical cancer mortality.....	45
Table 4 Normality of distribution test: Shapiro-Wilk test for the variable Colorectal cancer mortality.....	47
Table 5 Normality of distribution test: Shapiro-Wilk test for the variable Participation in breast cancer screening test.....	48
Table 6 Normality of distribution test: Shapiro-Wilk test for the variable Participation in cervical cancer screening test.....	49
Table 7 Normality of distribution test: Shapiro-Wilk test for the variable Participation in colorectal cancer screening test.....	51
Table 8 Normality of distribution test: Shapiro-Wilk test for the variable Cardiovascular disease mortality.....	52
Table 9 Normality of distribution test: Shapiro-Wilk test for the variable GDP (in EUR billion).....	54
Table 10 Normality of distribution test: Shapiro-Wilk test for the variable Expenditure in healthcare by % of GDP.....	55
Table 11 Pearson's correlation analysis for testing the relationship between Participation in breast cancer screening test and Breast cancer mortality.....	57
Table 12 Spearman's correlation analysis for testing the relationship between Participation in cervical cancer screening test and Cervical cancer mortality.....	62

Table 13 Spearman's correlation analysis for testing the relationship between Participation in colorectal cancer screening test and Colorectal cancer mortality.	65
Table 14 Spearman's correlation analysis for testing the relationship between GDP and Participation in breast cancer screening test.	67
Table 15 Spearman's correlation analysis for testing the relationship between GDP and Participation in cervical cancer screening test.	70
Table 16 Spearman's correlation analysis for testing the relationship between GDP and Participation in colorectal cancer screening test.	72
Table 17 Spearman's correlation analysis for testing the relationship between GDP and Cardiovascular diseases mortality.	75
Table 18 Spearman's correlation analysis for testing the relationship between GDP and Breast cancer mortality.	78
Table 19 Spearman's correlation analysis for testing the relationship between GDP and Cervical cancer mortality.	81
Table 20 Spearman's correlation analysis for testing the relationship between GDP and Colorectal cancer mortality.	84
Table 21 Spearman's correlation analysis for testing the relationship between Healthcare expenditure in % of GDP and Cardiovascular diseases mortality.	86
Table 22 Pearson's correlation analysis for testing the relationship between Healthcare expenditure in % of GDP and Breast cancer mortality.	88
Table 23 Spearman's correlation analysis for testing the relationship between Healthcare expenditure in % of GDP and Cervical cancer mortality.	91
Table 24 Spearman's correlation analysis for testing the relationship between Healthcare expenditure in % of GDP and Colorectal cancer mortality.	94
Table 25 Multiple regression analysis (x1 GDP, x2 Participation in breast cancer screening test, y Breast cancer mortality).	97
Table 26 Multiple regression analysis (x1 GDP, x2 Participation in cervical cancer screening test, y Cervical cancer mortality).	100
Table 27 Multiple regression analysis (x1 GDP, x2 Participation in colorectal cancer screening test, y Colorectal cancer mortality).	102
Table 28 Comparison of the cancer types and results of a multiple linear regression.	106
Table 29 Multiple regression analysis (x1 Healthcare expenditure in % of GDP, x2 Participation in breast cancer screening test, y Breast cancer mortality).	109
Table 30 Multiple regression analysis (x1 Healthcare expenditure in % of GDP, x2 Participation in cervical cancer screening test, y Cervical cancer mortality).	112

Table 31 Multiple regression analysis (x1 Healthcare expenditure in % of GDP, x2 Participation in colorectal cancer screening test, y Colorectal cancer mortality).	115
Table 32 Tools that analyze patient history, lifestyle, and genetic data to predict the likelihood of developing cancer (author's summary based on existing market solutions).....	127
Table 33 Cardiovascular Monitoring & Prevention Apps (author's summary based on existing market solutions).....	132

LIST OF FIGURES

Figure 1 Levels of disease prevention (Source: The Future Dentistry, 2026)	17
Figure 2 Participation in breast cancer screening programme (Source: Eurostat, 2023)	21
Figure 3 Participation in cervical cancer screening programme (Source: Eurostat, 2023).....	23
Figure 4 Participation in colorectal screening programme (Source: Eurostat, 2023).....	26
Figure 5 Risk factors for CVD (Source: Kahn Longevity Center, 2026).....	29
Figure 6 Economic burden of CVD in EU countries (Source: Luengo-Fernandez et al., 2023).....	32
Figure 7 Estimated macroeconomic costs of cancer, 2020-2050 (Source: Chen et al., 2023).....	37
Figure 8 Histogram on the normality of distribution of the variable Breast cancer mortality.....	44
Figure 9 Quantile-Quantile Plot on the normality of distribution variable Breast cancer mortality.....	45
Figure 10 Histogram on the normality of distribution of the variable Cervical cancer mortality.....	46
Figure 11 Quantile-Quantile Plot on the normality of distribution variable Cervical cancer mortality.....	46
Figure 12 Histogram on the normality of distribution of the variable Colorectal cancer mortality.....	47

Figure 13 Quantile-Quantile Plot on the normality of distribution variable Colorectal cancer mortality.....	48
Figure 14 Histogram on the normality of distribution of the variable Participation in breast cancer screening test.....	48
Figure 15 Quantile-Quantile Plot on the normality of distribution variable Participation in breast cancer screening test.....	49
Figure 16 Histogram on the normality of distribution of the variable Participation in cervical cancer screening test.....	50
Figure 17 Quantile-Quantile Plot on the normality of distribution variable Participation in cervical cancer screening test.....	50
Figure 18 Histogram on the normality of distribution of the variable Participation in colorectal cancer screening test.....	51
Figure 19 Quantile-Quantile Plot on the normality of distribution variable Participation in colorectal cancer screening test.....	52
Figure 20 Histogram on the normality of distribution of the variable Cardiovascular disease mortality.....	53
Figure 21 Quantile-Quantile Plot on the normality of distribution variable Cardiovascular disease mortality.....	53
Figure 22 Histogram on the normality of distribution of the variable GDP (in EUR billion).....	54
Figure 23 Quantile-Quantile Plot on the normality of distribution variable GDP (in EUR billion).....	55
Figure 24 Histogram on the normality of distribution of the variable Expenditure in healthcare by % of GDP.....	56
Figure 25 Quantile-Quantile Plot on the normality of distribution variable Expenditure in healthcare by % of GDP.....	56
Figure 26 Line Fit Plot for testing the relationship between Participation in breast cancer screening test and Breast cancer mortality.....	57
Figure 27 Line Fit Plot for testing the relationship between Participation in cervical cancer screening test and Cervical cancer mortality.....	62
Figure 28 Line Fit Plot for testing the relationship between Participation in colorectal cancer screening test and Colorectal cancer mortality.....	65
Figure 29 Line Fit Plot for testing the relationship between GDP and Participation in breast cancer screening test.....	67
Figure 30 Line Fit Plot for testing the relationship between GDP and Participation in cervical cancer screening test.....	70

Figure 31 Line Fit Plot for testing the relationship between GDP and Participation in colorectal cancer screening test.....	72
Figure 32 Line Fit Plot for testing the relationship between GDP and Cardiovascular diseases mortality.....	75
Figure 33 Line Fit Plot for testing the relationship between GDP and Breast cancer mortality	78
Figure 34 Line Fit Plot for testing the relationship between GDP and Cervical cancer mortality.....	81
Figure 35 Line Fit Plot for testing the relationship between GDP and Colorectal cancer mortality.....	84
Figure 36 Line Fit Plot for testing the relationship between Healthcare expenditure in % of GDP and Cardiovascular diseases mortality.....	86
Figure 37 Line Fit Plot for testing the relationship between Healthcare expenditure in % of GDP and Breast cancer mortality.....	89
Figure 38 Line Fit Plot for testing the relationship between Healthcare expenditure in % of GDP and Cervical cancer mortality.....	91
Figure 39 Line Fit Plot for testing the relationship between Healthcare expenditure in % of GDP and Colorectal cancer mortality.....	94

List of abbreviations

AF - Atrial fibrillation

AI – Artificial intelligence

ALVD - Asymptomatic Left Ventricular Dysfunction

ASCVD - Atherosclerotic Cardiovascular Disease

CDSS - Clinical Decision Support Systems

CIN - Cervical intraepithelial neoplasia

CRC - Colorectal cancer

CT - Computed Tomography

CVD - Cardiovascular disease

DALY - Disability-adjusted life years

DNA - Deoxyribonucleic acid

ECG - Electrocardiogram

ECIBC - European Commission Initiative on Breast Cancer

ERG - Employee resource groups

EU – European Union

FIT - Fecal immunochemical testing

FOBT - Fecal occult blood testing

GDP - Gross Domestic Product

GLOBOCAN - Project of the International Agency for Research on Cancer

HPC - High-performance computing

HPV - Human papillomavirus

IHD - Ischaemic heart disease

MCED – Multi Cancer Early Detection

OECD - Organisation for Economic Co-operation and Development

RPM - Remote patient monitoring

UNICEF - United Nations Children's Fund

WHO - World Health Organization

CHAPTER I: INTRODUCTION

1.1 Introduction

Business-oriented research in healthcare may improve efficiency and financial sustainability, enhance patient care, ensure competitive advantage, and serve for quality decision making. Especially with the application in hospital operations, digital health, promotion of specific tests, etc. The association between economic performance, public health initiatives and health outcomes is one of a key area of research in understanding the well-being of population. Gross Domestic Product (GDP) is a primary measure of a country's economic activity, and key variables influencing it include consumer spending, business investment, government spending, and net exports (exports minus imports). In the European Union (EU), where the nations exhibit diverse economics landscapes and healthcare systems, the interaction between Gross Domestic Product, participation in national cancer screening programmes and mortality rates from cardiovascular diseases (CVD) provides valuable insights into the efficiency and impact of public health interventions. GDP plays a significant role in shaping a healthcare budget, the accessibility of health services and the development of public health policies. Several studies have shown that higher GDP correlates with better healthcare infrastructure and better access to health services (Heijink et al., 2013; OECD, 2023). National healthcare expenditure is the total amount a country spends on health goods and services, often measured as a percentage of GDP, broken down by funding sources (private insurance, government programs like Medicare/Medicaid) and service types (hospital, physician, drugs). In the EU, public spending dominates healthcare, typically covering around 77% of total expenditure, with private spending making up the remaining 23%, though these figures fluctuate slightly by year and country. In 2023, total EU health spending was about 10.0% of GDP, with major shares going to hospitals and outpatient services, financed heavily by compulsory schemes (like social security) and government funds. While Germany, France, and Austria lead in expenditure relative to GDP, countries like Romania and Hungary spend less.

1.1.1 The role of cancer screening programmes

According to the World Health Organization (2024) health is a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity. Now, health promotion is of growing importance in the effective prevention and management of public health problems. Despite being some of the most widespread and expensive health conditions, chronic diseases are largely preventable. Prevention of chronic diseases requires a multisectoral, lifelong approach. There are three levels of disease prevention (figure 1).

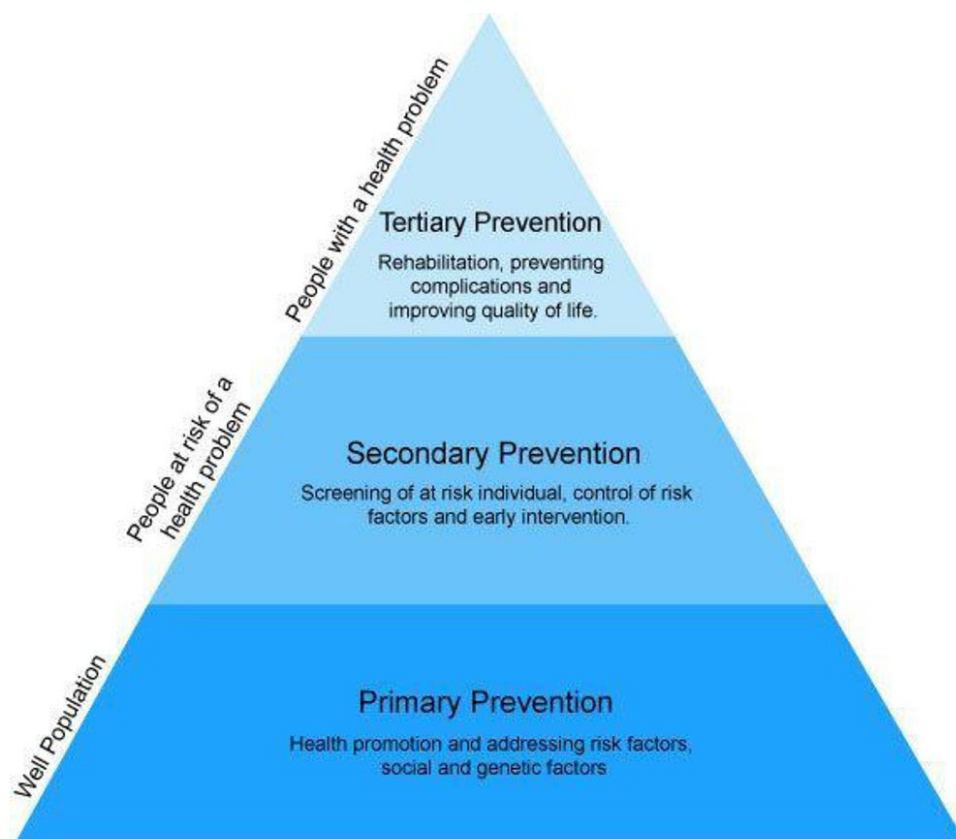


Figure 1. Levels of disease prevention (Source: The Future Dentistry, 2026)

Primary prevention involves actions taken before the onset of disease to eliminate or reduce the risk of its occurrence. It focuses on interventions during the pre-pathogenesis phase and emphasizes the promotion of positive health to support socially and economically productive lives. This level of prevention is achieved through health promotion, specific protection, nutritional measures, and lifestyle and behavioral modifications.

Secondary prevention focuses on the early detection of disease in apparently healthy individuals who have subclinical conditions. At this stage, pathological changes are present without obvious symptoms, making the disease difficult to detect during routine clinical visits. Screening programs are the primary approach used in secondary prevention.

Tertiary prevention is applied when a disease has progressed beyond the early stages and symptoms are present. It focuses on reducing impairments and disabilities, limiting complications, and promoting rehabilitation and adaptation to chronic or irreversible conditions. This level of prevention targets the clinical and outcome stages of disease to minimize severity and long-term consequences.

Cancer, caused by the uncontrolled growth of abnormal cells, remains one of the leading causes of death worldwide despite advances in screening, early diagnosis, and treatment. Screening enables early detection of cancer and improves the chances of successful and curative treatment. Cancer screening is defined as the systematic application of a test or examination to asymptomatic individuals in order to identify disease at an early stage, when treatment is more effective and outcomes are improved (Grimes and Schulz, 2002). There are two main types: organised and opportunistic screening. Opportunistic screening occurs when individuals are screened during routine healthcare visits, without systematic invitation or population registers. It depends largely on patient initiative or physician recommendation. Although some EU countries historically relied on opportunistic screening, particularly for cervical cancer, EU policy increasingly promotes organised approaches due to better effectiveness and equity (European Commission, 2022).

In contrast to opportunistic screening, population-based programmes are characterized by defined target populations, systematic invitation procedures, standardized screening protocols, quality assurance mechanisms, and continuous monitoring and evaluation (European Commission, 2022).

National cancer screening programmes are government-led initiatives to detect early-stage cancers before symptoms appear, using tests like mammograms, HPV/Pap tests, FIT kits, and low-dose CT scans to enable early treatment and improve outcomes. National cancer screening programmes have been shown to be effective in reducing mortality from certain cancers through early detection and treatment. The theoretical and practical foundations of cancer screening are rooted in the principles articulated by Wilson and Jungner (1968), which remain central to screening policy in Europe. These principles emphasize that screening should address an important health problem, use an acceptable and accurate test, detect disease at a recognizable early stage, and lead to improved health outcomes through effective treatment. The World Health Organization and other public health bodies recommend screening programmes for various cancers, while most of the EU countries conduct screening programmes for breast, cervical and colorectal cancer.

Breast cancer is the most diagnosed cancer among women in the EU and a leading cause of cancer-related death. Mammography screening has been shown to reduce breast cancer mortality by enabling earlier diagnosis and treatment, particularly among women aged 50–69 years (IARC, 2016). Mammography was systematically evaluated through randomized controlled trials, notably the Health Insurance Plan of Greater New York (HIP) Study, the Malmö trial, and the Swedish Two-County Trial (Croswell et al., 2010). Despite certain methodological weaknesses, each of these studies demonstrated a reduction in breast cancer mortality among women who underwent screening.

The EU has played a significant role in shaping national cancer screening policies through the establishment of common standards, recommendations, and monitoring frameworks. A major milestone was the adoption of the Council Recommendation on Cancer Screening in 2003, which called on member states to implement population-based screening programmes for breast, cervical, and colorectal cancer, in accordance with evidence-based guidelines and quality assurance standards (Council of the European Union, 2003). This recommendation marked a shift from fragmented and opportunistic screening practices toward organized public health programmes.

In recognition of scientific and technological advances, as well as persistent inequalities in screening coverage and outcomes, the Council Recommendation was updated in 2022. The revised recommendation reaffirmed the importance of organized screening and set an ambitious target that 90% of the eligible EU population should be offered screening for breast, cervical, and colorectal cancer by 2025 (European Commission, 2022).

Most EU member states have established national or regional screening programmes for breast, cervical, and colorectal cancer, although the level of organization, coverage, and effectiveness varies considerably. Breast cancer screening programmes based on mammography are the most widely implemented, with the majority of member states offering biennial screening to women within defined age ranges. Cervical cancer screening programmes are undergoing a transition from cytology-based approaches to primary HPV testing, reflecting evidence of higher sensitivity and longer screening intervals (Arbyn et al., 2020). Colorectal cancer screening programmes, commonly based on FIT or guaiac-based fecal occult blood tests followed by colonoscopy, are less uniformly established and often exhibit lower participation rates (OECD/European Union, 2024).

1.1.2 Breast cancer screening

Breast cancer represents the most commonly diagnosed cancer in women in the European Union and is a leading cause of cancer mortality. Early detection through systematic screening has been shown to reduce mortality by enabling diagnosis at stages where treatment is more effective. Across the EU, organized breast cancer screening programmes play a central role in national cancer control strategies, reflecting both European-level recommendations and country-specific health system structures. At the EU level, the evidence-based guideline development process, coordinated through the European Commission Initiative on Breast Cancer (ECIBC), has established standardized recommendations for breast cancer screening. According to Knowledge4Policy (2024) and Europa Donna (2025), for women without symptoms and at average risk, biennial mammography is recommended for ages 50-69 (strong recommendation), while conditional recommendations support offering screening at ages 45-49 (every 2-3 years) and 70-74 (every 3 years). Mammography is a specialized medical imaging technique that uses low-dose X-rays to examine the human breast for early detection of breast cancer and other abnormalities. It remains the gold standard for population-based breast cancer screening (American Cancer Society, 2024; European Commission, 2022). The aim of mammography is to identify tumors before clinical symptoms appear, which improves survival rates (OECD,2022).

Participation in screening should be voluntary and based on informed choice, with women receiving information on both the potential benefits and harms of screening (European Commission, 2022; Knowledge4Policy, 2024). Organized programmes ideally use centralized invitations with quality assurance mechanisms, including double reading of mammograms and standardized reporting (European Commission, 2022; European Guidelines).

Despite common EU guidance, implementation of breast cancer screening varies across member states in terms of organization, age range, and uptake. There is a difference in response to breast cancer screening tests between EU countries (figure 2).

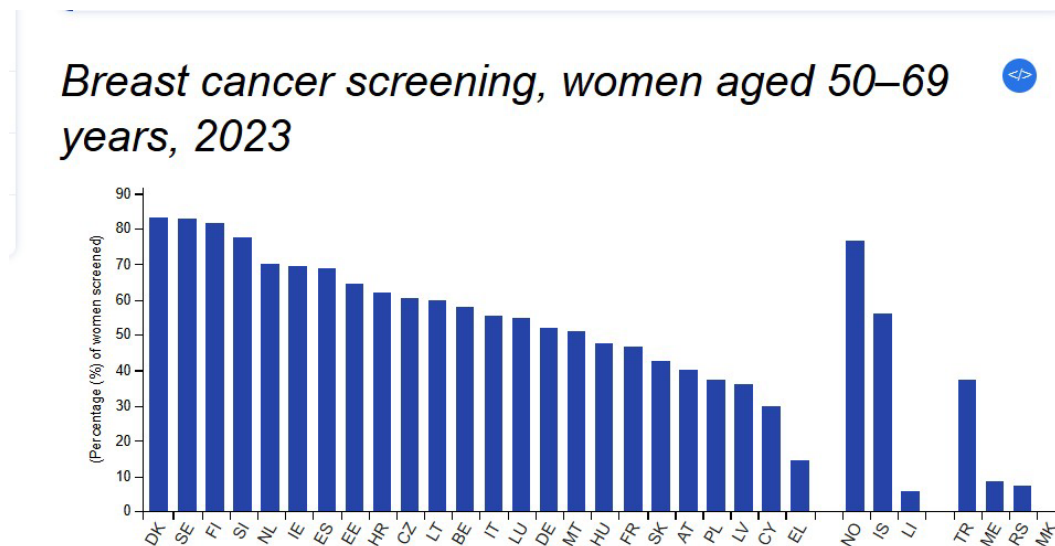


Figure 2. Participation in breast cancer screening programme (Source: Eurostat, 2023)

Most EU countries have established population-based screening programmes where eligible women are actively invited to attend mammography at specified intervals. However, there is heterogeneity in governance:

- National programmes: Countries such as Croatia, Finland, and Greece have national implementation of screening protocols (OECD, 2022).
- Regional programmes: In Belgium, Italy, and Sweden, screening is organized by regional health authorities, resulting in variation within countries (OECD, 2022).

Breast cancer screening programmes across the EU are grounded in robust evidence demonstrating the benefits of early detection. While EU-level guidelines provide a harmonized framework, implementation reflects national contexts and health system structures. Ongoing efforts to expand age criteria, improve participation, and enhance quality assurance are critical to achieving equitable and effective screening outcomes across the Union.

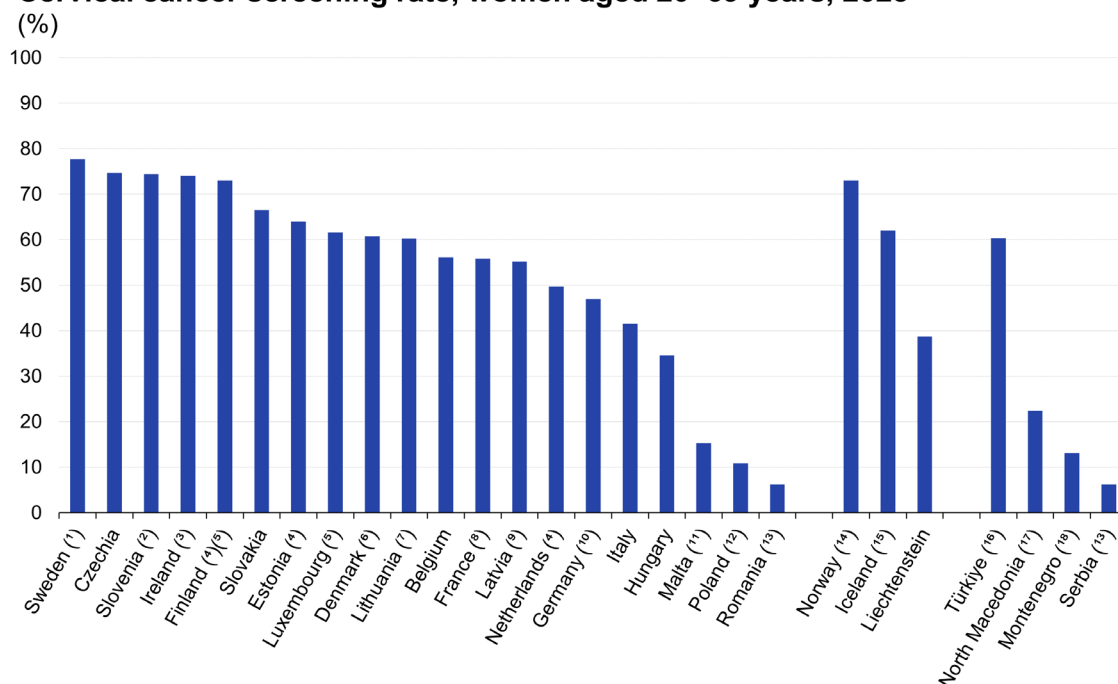
1.1.3 Cervical cancer screening

Cervical cancer screening constitutes a central component of secondary prevention strategies aimed at reducing the incidence and mortality of cervical cancer through early detection of precancerous lesions and early-stage invasive disease. Persistent infection with high-risk oncogenic human papillomavirus (HPV) types is a necessary cause of nearly all cases of cervical cancer. The causal relationship between HPV and cervical carcinogenesis was conclusively demonstrated by zur Hausen (2002), establishing the molecular basis for both HPV-based screening and prophylactic vaccination. Cervical cancer screening represents one of the most established and effective secondary prevention strategies in public health. Within the European Union (EU), screening policies have evolved substantially over the past two decades, transitioning from predominantly opportunistic models toward organized, population-based programmes supported by EU-level recommendations and quality assurance frameworks.

Historically, cervical screening in Europe was cytology-based (Papanicolaou smear). However, robust evidence demonstrating the higher sensitivity of HPV testing has driven a paradigm shift toward HPV-based primary screening.

The Papanicolaou (Pap) smear, developed by George Papanicolaou, involves microscopic evaluation of exfoliated cervical epithelial cells to identify cytological abnormalities indicative of cervical intraepithelial neoplasia (CIN). Organized cytology-based screening programmes have led to marked reductions in cervical cancer incidence and mortality in high-income countries (IARC, 2005). In EU countries, participation in cervical cancer screening programs varies from 6% to 77% (figure 3).

Cervical cancer screening rate, women aged 20–69 years, 2023



Note: programme-based data. The rate shown is the proportion of women aged 20–69 years who have been screened for cervical cancer within the previous 3 years (or according to the specific screening frequency recommended in each country). This is shown as a proportion of women eligible for an organised screening programme. Bulgaria, Greece, Croatia, Cyprus and Austria: no cervical cancer screening programme. Spain: not available.

⁽¹⁾ Women aged 23–64 years.

⁽²⁾ Women aged 20–64 years.

⁽³⁾ Share of women aged 25–65 years screened within the previous 5 years. Provisional.

⁽⁴⁾ Share of women aged 30–65 years who received an invite and were screened during the year.

⁽⁵⁾ Provisional.

⁽⁶⁾ Share of women aged 23–64 years who received an invite and were screened during the year. 2021.

⁽⁷⁾ Women aged 25–60 years.

⁽⁸⁾ Share of women aged 25–65 years screened within the previous 3 years. Denominator is entire population.

⁽⁹⁾ Share of women aged 25–70 years who received an invite and were screened during the year.

⁽¹⁰⁾ Estimate.

⁽¹¹⁾ Women aged 25–43 years. Denominator is invited women.

⁽¹²⁾ Women aged 25–59 years.

⁽¹³⁾ Women aged 25–64 years.

⁽¹⁴⁾ Women aged 25–69 years.

⁽¹⁵⁾ Share of women aged 23–65 years screened within the previous 3.5 years.

⁽¹⁶⁾ Women aged 30–65 years.

⁽¹⁷⁾ 2021.

⁽¹⁸⁾ Women aged 30–50 years.

Source: Eurostat (online data code: hlth_ps_prev)

Figure 3. Participation in cervical cancer screening programme (Source: Eurostat, 2023)

HPV DNA testing identifies the presence of high-risk HPV genotypes associated with cervical carcinogenesis. Primary HPV testing detects high-risk HPV genotypes responsible for the majority of cervical cancers. Compared with cytology, HPV testing offers:

- Higher sensitivity for high-grade cervical intraepithelial neoplasia (CIN2+)
- Longer negative predictive value
- Extended screening intervals (typically five years)

Cytology is increasingly used as a triage test following a positive HPV result. Many EU member states have completed or are undergoing transition from cytology-based to HPV-based screening. The European Code Against Cancer, a widely referenced public health guideline, states that national screening programmes in EU states typically invite individuals for cervical screening starting between 25 and 30 years of age when cytology is used, or from 30-35 years when primary HPV testing is employed; intervals are usually every 3-5 years, and invitations continue until 60-65 years of age.

1.1.4 Colorectal cancer screening

Colorectal cancer is among the most frequently diagnosed cancers globally and constitutes a significant contributor to cancer mortality. According to the International Agency for Research on Cancer (2016), colorectal cancer ranks third in incidence and second in cancer-related deaths worldwide. Estimates from GLOBOCAN indicate approximately 1.9 million new cases and over 900,000 deaths annually (Sung et al., 2021).

Organized colorectal cancer screening programs significantly reduce mortality through early detection and removal of precancerous lesions (Arnold et al., 2017). Screening modalities include:

- Fecal occult blood testing (FOBT)
- Fecal immunochemical testing (FIT)
- Colonoscopy
- Flexible sigmoidoscopy.

FOBT is a non-invasive test that detects hidden (occult) blood in stool, which may indicate the presence of colorectal neoplasia or polyps. Traditional guaiac-based FOBT requires dietary restrictions to reduce false positives. FOBT has been widely used in population-based screening programmes and has been shown to reduce colorectal cancer mortality by enabling early detection (Hewitson et al., 2008). However, its sensitivity for advanced adenomas is moderate, and positive results require follow-up colonoscopy.

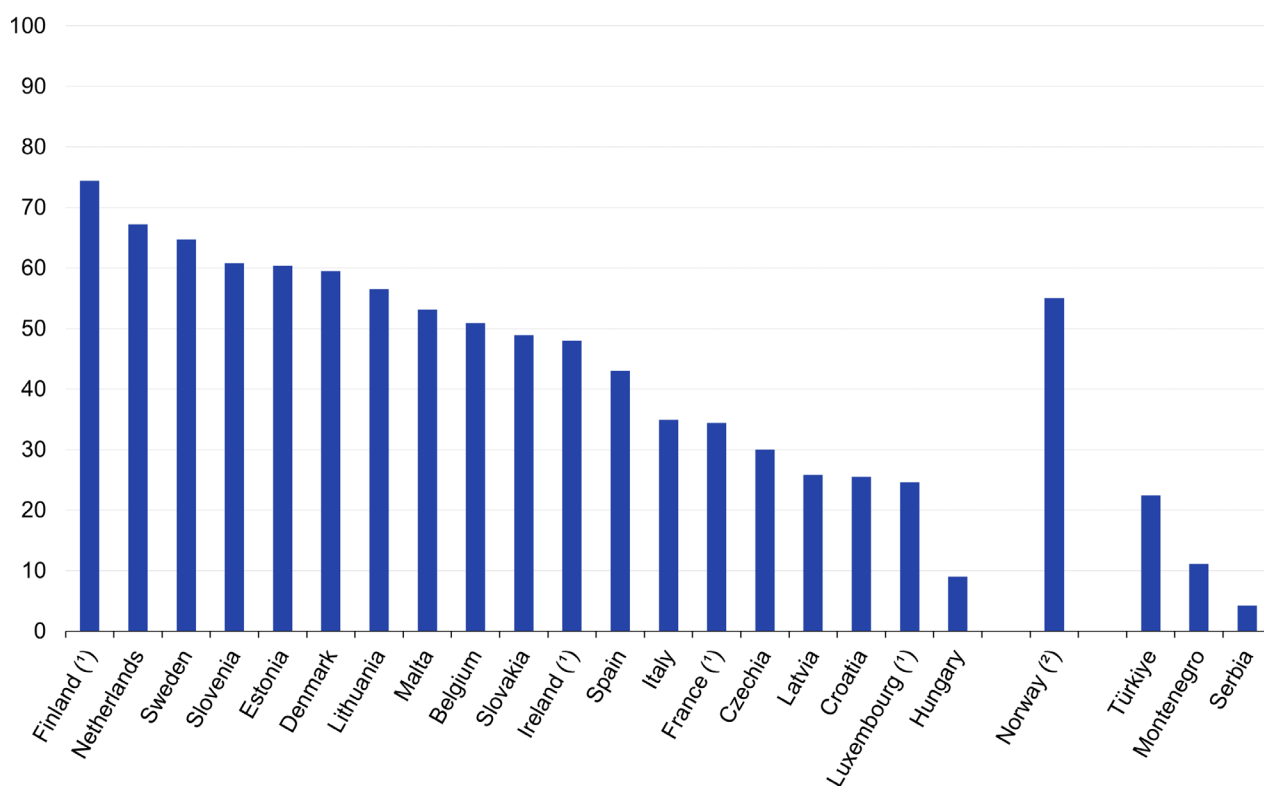
FIT is a more advanced stool-based test that uses antibodies to detect human hemoglobin in feces. Unlike FOBT, FIT does not require dietary restrictions and is more specific for lower gastrointestinal bleeding. FIT has higher sensitivity and specificity for detecting colorectal cancer and advanced adenomas compared to guaiac-based FOBT, and it has become the preferred non-invasive screening method in many national programmes (Imperiale et al., 2014).

Colonoscopy is an endoscopic procedure that allows direct visualization of the entire colon and rectum. It enables both detection and removal of precancerous polyps in a single procedure, making it the gold standard for colorectal cancer screening. Colonoscopy has the highest sensitivity for detecting colorectal neoplasia and provides both diagnostic and therapeutic functions (Zauber et al., 2012). Limitations include higher cost, procedural risks, and the need for bowel preparation and sedation.

Flexible sigmoidoscopy is an endoscopic examination of the rectum and distal colon. It allows detection and removal of polyps in the distal colon, but it does not visualize the entire colon. Compared to colonoscopy, flexible sigmoidoscopy is less invasive, requires less preparation, and carries fewer procedural risks. Screening with sigmoidoscopy has been associated with reductions in distal colorectal cancer incidence and mortality, but its effectiveness is limited for proximal colon lesions (Atkin et al., 2010). In EU countries, participation in colorectal cancer screening programs varies from 9% to 74% (figure 4).

Colorectal cancer screening rate, 2023

(%)



Note: programme-based data. The rate shown is the proportion of the target population who have been screened for colorectal cancer within the previous 2 years (or according to the specific screening frequency recommended in each country). This is shown as a proportion of people eligible for an organised screening programme. Bulgaria, Greece, Cyprus, Austria and Romania: no colorectal screening programme. Germany and Poland: not available.

⁽¹⁾ Provisional.

⁽²⁾ Definition differs.

Source: Eurostat (online data code: hlth_ps_prev)

Figure 4. Participation in colorectal screening programme (Source: Eurostat, 2023)

1.1.5 Cardiovascular diseases

Cardiovascular diseases remain the leading cause of mortality and a major cause of morbidity in the EU (Wilkins et al., 2017). These diseases include a range of conditions that affect the heart and blood vessels, including coronary artery disease, heart attack, stroke, heart failure and arrhythmias. They represent the leading cause of mortality globally and remain a dominant contributor to morbidity, disability and healthcare expenditure across high-, middle- and low-income countries (World Health Organization, 2023). Within the European Union (EU), cardiovascular disease continues to impose a substantial burden in terms of mortality, morbidity, disability-adjusted life years (DALYs), and healthcare expenditure. Despite considerable advances in prevention, pharmacotherapy, interventional cardiology, and acute stroke care, CVD remains responsible for approximately one-third of all deaths across EU member states. Western and Southern European countries such as France, Spain and Italy report comparatively low age-standardized mortality rates from circulatory diseases. In contrast, substantially higher rates are observed in Central and Eastern European countries, including Bulgaria, Romania, Latvia and Lithuania (Eurostat, 2023). However, the burden is unevenly distributed, with pronounced geographical, socioeconomic, and gender disparities.

The most common subtypes of CVD in the EU are:

- Ischaemic heart disease (IHD)
- Stroke (ischaemic and haemorrhagic)
- Heart failure
- Hypertensive heart disease

Ischaemic heart disease and stroke together account for the largest proportion of cardiovascular deaths. In several member states, IHD alone represents 12-15% of all deaths. In addition to mortality, CVD contributes significantly to chronic disability. Stroke is a leading cause of long-term functional impairment in adults, while heart failure is associated with high rates of hospitalization, reduced quality of life, and frequent readmissions. The burden of CVD is further reflected in healthcare spending, estimated at over €280 billion annually across the EU when direct medical costs and productivity losses are combined (European Commission, 2022).

Cardiovascular diseases are mainly caused by atherosclerosis, a chronic inflammatory process characterized by lipid accumulation and plaque formation within the arterial wall. Endothelial dysfunction, oxidative stress, dyslipidemia, and immune activation play a central role in plaque formation and progression. Plaque rupture and thrombosis are the primary mechanisms underlying acute coronary syndromes and ischemic stroke (Libby et al., 2019). Hypertension contributes to arterial stiffness, left ventricular hypertrophy, and microvascular damage, thereby increasing the risk of myocardial infarction, stroke, heart failure, and chronic kidney disease. Similarly, diabetes mellitus accelerates atherogenesis through hyperglycemia-induced endothelial damage and proinflammatory pathways. Although the biological mechanisms are well established, other determinants such as socioeconomic status, health behaviors, urban design, food systems, and public policies also influence the development of CVD (Marmot et al., 2020). Therefore, CVD is not only a biomedical condition but also a social and structural phenomenon.

A large proportion of cardiovascular mortality in the EU is attributable to modifiable risk factors (figure 5). These include:

- Tobacco use
- Hypertension
- Hypercholesterolaemia
- Diabetes mellitus
- Obesity
- Physical inactivity
- Unhealthy diet (high salt, saturated fat, low fruit/vegetable intake)
- Harmful alcohol consumption
- Air pollution

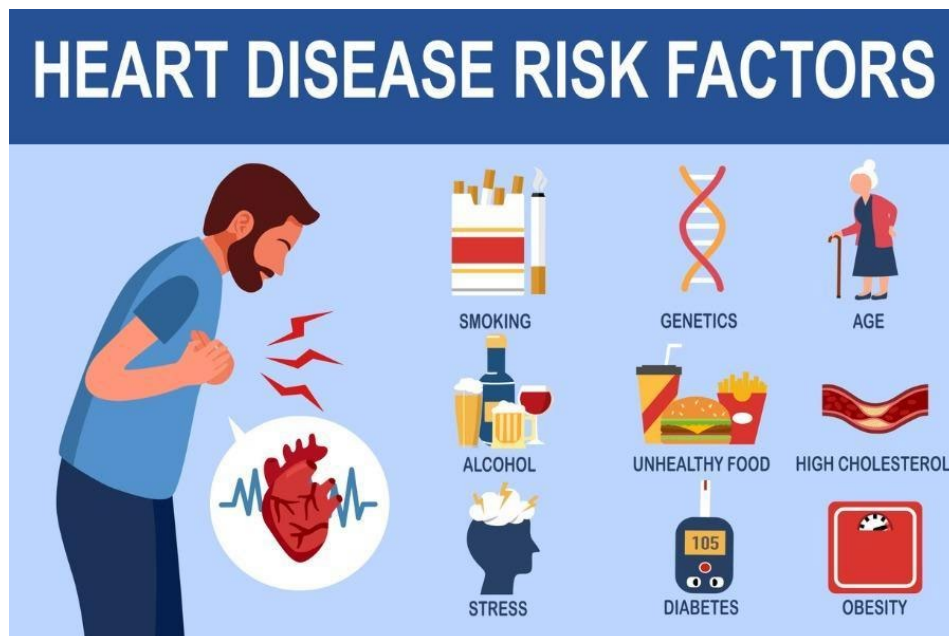


Figure 5. Risk factors for CVD (Source: Kahn Longevity Center, 2026)

Epidemiological modelling suggests that more than three-quarters of CVD deaths in Europe are linked to modifiable risk exposures (OECD/European Union, 2023). Smoking remains a leading preventable cause of cardiovascular mortality. Tobacco control policies have led to major declines in smoking in many Western EU countries, though prevalence remains high in parts of Eastern Europe. Meanwhile, obesity rates have increased steadily across almost all member states, posing a significant threat to future cardiovascular health gains. Cardiovascular mortality is strongly patterned by socioeconomic status. Lower educational attainment, income inequality, unemployment and material deprivation are consistently associated with higher CVD mortality rates.

1.2 Research Problem

State healthcare funding in the EU comes from two main sources: national governments and EU-level initiatives. The healthcare and business relationship involves applying business practices like financial management and operational efficiency to healthcare organizations, which is vital for delivering quality care and ensuring financial sustainability. While healthcare is fundamentally about patient well-being, its structure involves complex markets, government intervention, and the need for business-minded approaches to manage costs, improve services, and foster innovation through entrepreneurship and strategic partnerships. Especially from the business perspective, to date, no systematic research has been conducted on the association of GDP, national healthcare expenditure and participation in national cancer screening programmes with mortality from cancer and cardiovascular diseases in the EU countries so that would be the main contribution of this study, which may serve as one of the potential directions for both healthcare and business benefit of the EU countries.

1.3 Purpose of Research

While GDP has a well-established relation to healthcare quality and access, its impact on the effectiveness of national cancer screening programmes and mortality from cardiovascular diseases requires further research. This study aims to explore the dynamic relationship between GDP, national healthcare expenditure, participation in national cancer screening programmes and mortality of cardiovascular diseases in EU countries. By analyzing these factors in a comparative context, we can identify patterns and correlations that might give a lot of information for future health policies and economic strategies for improving public healthcare and health outcomes in the EU countries as well as to identify some business-related opportunities among the extensive healthcare industry.

1.4 Significance of the Study

This research will contribute to fill a lack of conducted systematic research on association of GDP, national healthcare expenditure and participation in national cancer screening programmes with mortality from cancer and cardiovascular diseases in the EU countries, especially with business-related recommendations provided.

1.5 Research Objectives

The focus of this research is a comprehensive study on the association of GDP, national healthcare expenditure and participation in national cancer screening programmes with mortality from cancer and cardiovascular diseases in the EU countries. The objectives of the study are:

1. To determine the association between GDP and participation in the national cancer screening programmes in EU countries.
2. To determine the association between GDP and mortality of cardiovascular diseases in EU countries.
3. To determine the association between participation in the national cancer screening programmes and mortality of related illnesses in EU countries.
4. To determine the association between the national healthcare expenditure and mortality of cardiovascular diseases in EU countries.
5. To determine the association between the national healthcare expenditure and cancer mortality in EU countries.
6. To determine the association between GDP, participation in the national cancer screening programmes and cancer mortality in EU countries.
7. To determine the association between the national healthcare expenditure, participation in the national cancer screening programmes and cancer mortality in EU countries.
8. To provide business-related recommendations for the healthcare industry in this particular domain.

Chapter II: REVIEW OF LITERATURE

2.1 Review of literature

Non-communicable diseases, particularly cancer and cardiovascular diseases (CVDs), remain the leading causes of mortality across European Union (EU) countries. Considerable attention has therefore been directed towards understanding how macroeconomic factors, healthcare investment, and preventive health policies, such as national cancer screening programmes, are associated with variations in mortality outcomes across member states. Across EU countries, non-communicable diseases, especially cancer and cardiovascular diseases, represent major health burdens with substantial economic impacts. Cardiovascular diseases remain the leading cause of mortality worldwide. According to the WHO (2024) 17.9 million people died from CVDs in 2019, representing 32% of all global deaths. In countries of EU CVD causes each year over 1.8 million deaths, that accounts for 37% of all deaths in countries of EU (Wilkins et al., 2017). CVDs are also a major cost for the healthcare system. In the European Union, these conditions are estimated to generate €111 billion in annual healthcare expenditures, plus a further €54 billion due to productivity losses (Spiteri and von Brockdorff, 2019). Figure 6 shows that these expenditures were even higher in 2021.

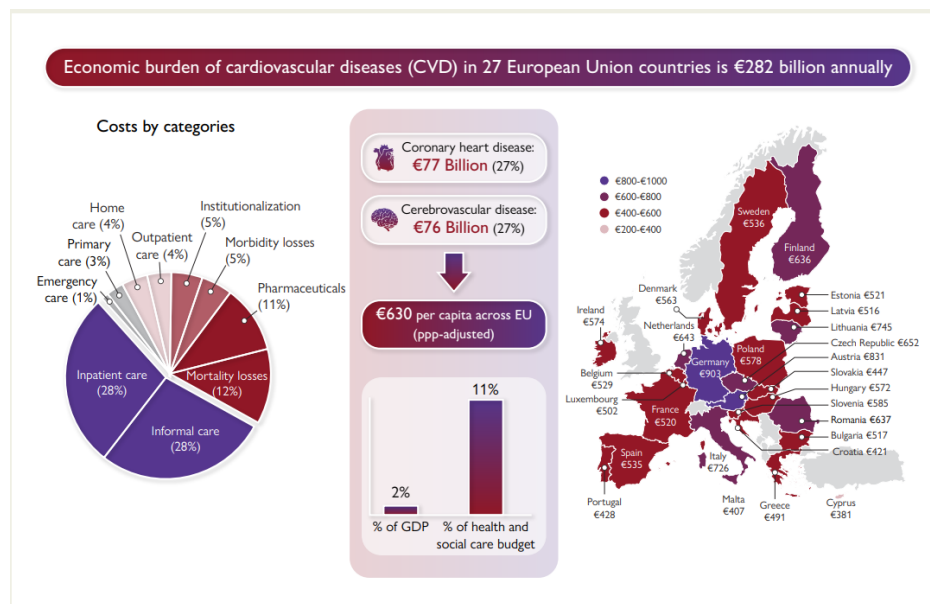


Figure 6. Economic burden of CVD in EU countries (Source: Luengo-Fernandez et al., 2023)

Gross Domestic Product is widely regarded as a key structural determinant of population health, influencing health outcomes through income levels, public sector capacity, and social welfare provision. A substantial body of empirical research has examined the association between economic growth and mortality, with mixed findings. GDP is commonly used as an indicator of national wealth and living standards, reflecting a country's capacity to invest in social services, infrastructure and healthcare systems (Bloom and Canning, 2000). Numerous cross-country studies demonstrate a positive relationship between GDP and life expectancy, alongside lower overall mortality rates (Deaton, 2003). Within the EU, higher-income countries generally report lower age-standardized mortality rates from both cancer and cardiovascular diseases (Eurostat, 2023). This relationship is often attributed to improved access to healthcare, better education, healthier working conditions, and improved lifestyles (Marmot et al., 2008). However, several studies suggest that the association between GDP and health outcomes is subject to diminishing returns, particularly in high-income countries (Deaton, 2013). Beyond a certain threshold, further economic growth appears to contribute little to additional mortality reduction.

While higher GDP levels are generally associated with improved health infrastructure and access to medical care, several studies identify non-linear relationships between income and mortality, particularly for cardiovascular diseases (Sanmarchi et al., 2022). This evidence suggests that in earlier stages of development, economic growth may coincide with lifestyle changes that increase disease risk, before mortality declines at higher income levels as healthcare systems and preventive care improve. Suhrcke and Urban (2010) examined the relationship between deaths from cardiovascular diseases and economic growth across countries. Their results show that the effect of cardiovascular mortality on growth varies by income level. At the global level, the relationship is not uniform but changes along the income-per-capita spectrum. When countries are divided into low- and middle-income versus high-income groups, clear differences emerge. In high-income countries, higher cardiovascular mortality among the working-age population consistently leads to slower economic growth over the following five years.

There are different opinions and studies on how GDP affects cardiovascular disease mortality. Some studies say that countries with lower GDP have higher mortality from cardiovascular disease, while some say that countries with higher GDP have higher mortality. The association between CVD and GDP is complex and shaped by multiple interacting mechanisms. Higher GDP levels are often linked to improved health outcomes, including reduced CVD mortality, largely due to enhanced access to healthcare services and more advanced treatment options. In addition, greater economic prosperity is commonly associated with favourable socioeconomic conditions, such as higher educational attainment, which supports healthier behaviours and increased awareness of CVD-related risk factors. At the same time, environmental influences, including pollution and urbanization, may elevate CVD risk; however, wealthier countries are generally better positioned to invest in environmental improvements, such as green spaces, that promote physical activity and help offset these risks (Blázquez-Fernández and Cantarero-Prieto, 2025). One of the studies shows that the Central Europe, Eastern Europe and Central Asia region have the highest levels of cardiovascular disease mortality globally (Cesare et al., 2024). They also say that most high-income countries are marked by substantial behavioural risks, such as high intake of sodium and alcohol, frequent tobacco use, and insufficient physical activity. Another shows that countries that share the same GDP may have quite different health outcomes, meaning that health seems to be affected not only by the wealth of a society, but also by the distribution of wealth within that society (Dewan et al., 2019).

There was a one long-term study (Rosengren et al., 2019) about socioeconomic status and risk of cardiovascular disease in 20 low-income, middle-income, and high-income countries that followed participants. In the study they tracked participants for an average of 7.5 years. The researchers found that individuals with lower educational attainment in low- and middle-income countries faced a significantly higher risk of developing and dying from cardiovascular disease. One more study showed that there is a big connection between CVD mortality and poverty in low- and middle-income countries. CVDs are both a cause and a consequence of poverty, which means that they arise as a result of poor lifestyles among people who, due to poverty, cannot afford a better way of eating and taking care of themselves, and at the same time, the costs of treating these diseases only deepen poverty (Bovet and Paccaud, 2011).

One interesting study was made about association between GDP, mortality and healthcare spending in high-income countries (Sanmarchi et al., 2022). Study showed that higher mortality rates were associated with lower health care expenditure and increases in GDP were strongly associated with increases in health care spending. The authors found bi-directional relationships between GDP, mortality, and health spending. The bidirectional nature of relationships suggests a feedback loop: stronger economies allow more health investment, and better health may in turn support economic productivity.

Wealthier countries generally have greater resources to allocate toward health systems, potentially improving disease prevention and treatment. However, empirical evidence suggests that economic prosperity alone does not guarantee better health outcomes. For example, a recent econometric analysis across European countries found that while both GDP per capita and healthcare expenditure were positively related to cervical cancer outcomes, healthcare spending had a stronger and more consistent impact than GDP itself, indicating that targeted investment in health systems is more influential than general economic wealth in reducing mortality from specific conditions such as cancer (Aydin and Aydin, 2025). Moreover, GDP does not account for income distribution or health system efficiency. Countries with comparable GDP levels may display markedly different health outcomes, indicating that economic growth alone is insufficient to ensure improved population health without effective health policies and investments (WHO, 2019). Cancer is a growing health problem of today that affects the quality of life, economic losses and consequent shortening of life expectancy. It's known that it is the second leading cause of death worldwide. Between 2005 and 2015, the global incidence of cancer increased by 33%. Among men, the most frequently diagnosed cancer was prostate cancer, while breast cancer was the most common among women (Fitzmaurice and Global Burden of Disease Cancer Collaboration, 2018). In Europe, this problem is becoming more and more pronounced, so the solution is being tried to be found through organized screening tests for certain forms of cancer (Cancer Screening in the EU: 2nd Report on the Implementation of the Council Recommendation - European Commission, no date). The purpose of screening is to identify people in an apparently healthy population who are at higher risk of a health problem or a condition, so that an early treatment or intervention can be offered and thereby reduce the incidence and/or mortality of the health problem or condition within the population (Screening programmes: a short guide. Increase effectiveness, maximize benefits and minimize harm, no date).

National cancer screening programmes for breast cancer, cervical cancer and colorectal cancer are implemented in European Union countries. Unfortunately, they are not yet implemented in all EU countries for each of these types. Despite EU-wide recommendations, participation rates in national screening programmes vary considerably between countries, reflecting differences in health system organization, public awareness, accessibility, and socioeconomic inequalities (OECD/European Commission, 2024). Lower participation rates have been associated with delayed diagnoses and poorer outcomes, underscoring the importance of both coverage and uptake in achieving mortality reductions. To date, no systematic research has been conducted on the association between GDP and participation in national cancer screening programmes in all EU countries (one of the crucial identified gaps), especially with business-related recommendations provided, so that is something that this research would examine. There are several studies on specific type of cancer and participation in a national cancer screening programme, but not for all types and EU countries. One of them (Peintinger, 2019) says that all European states except the Russian Federation, Bulgaria, Greece, the Czechia and Slovak Republics have a national screening programme for breast cancer. They also say that there is inequality in the implementation and that is a result of variabilities in economic resources for health care. Something similar shows research about breast cancer screening programmes across the WHO European region (Altobelli et al., 2017) in which they found that low-income countries have a less efficient general organization and proportion of breast cancer screening programmes, while programmes are often absent in middle-income countries. There are some researches for other countries worldwide. Akinyemiju (2012) conducted research about socio-economic determinants of breast and cervical cancer screening in 15 low-income countries around the world. He came to conclusion that a cancer incidence and mortality rates have been declining in developed, western nations, while the cancer incidence and mortality of cancer have been increasing in a low-income country. Another research about cancer screening in a low- and middle-income countries showed that the most low and middle-income countries worldwide don't have organized cancer screening programmes (Sankaranarayanan, 2014). The health-service infrastructure, human resources and low health-service investments were mentioned as the potential reasons. For colorectal screening programme was made research about personal income and people's participation in that.

It showed that people who lived in high-income areas were more likely to participate in a colorectal screening programme than the people who live in a low-income areas (Decker et al., 2016). Helgestad et al. (2024) showed that individuals with lower socioeconomic status are less likely to participate in organized screening programmes, which can exacerbate mortality differences across populations. It shows that socioeconomic and demographic factors significantly influence participation in organised cancer screening programmes. The economic impact of cancer is substantial, driven by lost productivity, job displacement, labor shortages, and declines in capital investment (Chen et al., 2023). Figure 7 shows projections of expected macroeconomic costs due to cancer in the period from 2020 to 2050.

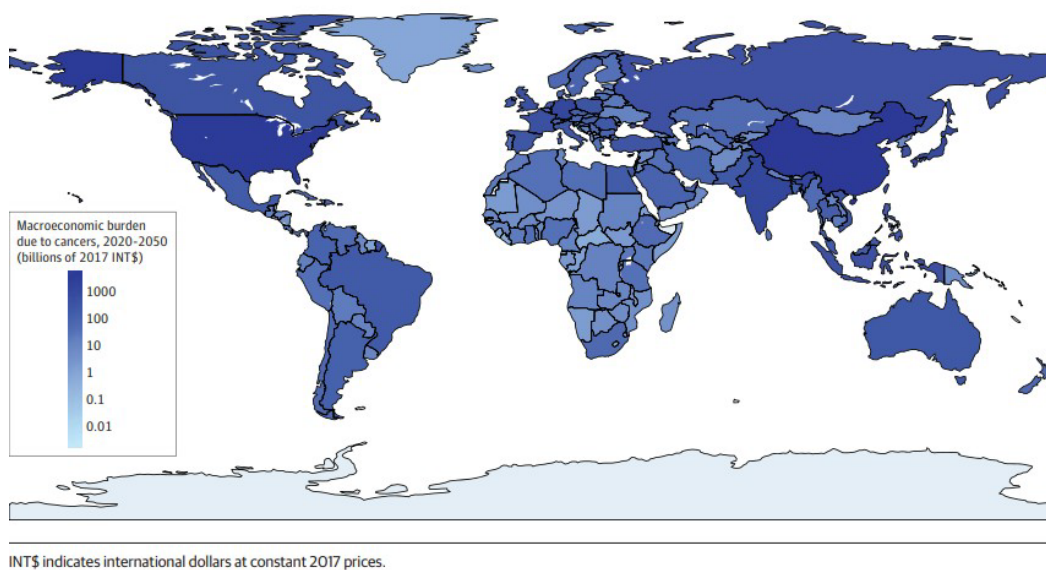


Figure 7. Estimated macroeconomic costs of cancer, 2020-2050 (Source: Chen et al., 2023)

An amount of empirical literature examines the relationship between macroeconomic conditions and health outcomes, consistently demonstrating that macroeconomic environments play a significant role in shaping population health, influencing both access to healthcare services and overall health outcomes. Ward et al. (2021) gave a conclusion that investing in cancer screening, diagnosis, and treatment has the potential to generate significant health and economic gains, particularly in low- and middle-income countries, where cancer survival rates are lower than in high-income countries. National healthcare expenditure is a more direct measure of investment in health than GDP, capturing spending on medical services, preventive care, infrastructure, and healthcare personnel. The literature consistently indicates an inverse association between healthcare expenditure and mortality from preventable and treatable conditions (Nixon and Ulmann, 2006; OECD, 2022).

In the EU context, higher healthcare expenditure per capita has been linked to improved cancer survival rates, reduced cardiovascular mortality, and better access to diagnostic and treatment services (Joumard et al., 2010). Increased spending is associated with earlier disease detection, shorter waiting times, and wider availability of advanced medical technologies, particularly in oncology and cardiology. However, evidence also suggests that increased healthcare spending does not always lead to proportional improvements in health outcomes. Studies highlight significant variation in efficiency across health systems, with some countries achieving better outcomes at lower levels of expenditure (Cylus et al., 2016). This suggests that the allocation and management of healthcare resources, rather than expenditure alone, play a crucial role in determining mortality outcomes.

2.2 Summary

GDP is commonly used as an indicator of national wealth and living standards, reflecting a country's capacity to invest in social services, infrastructure and healthcare systems (Bloom and Canning, 2000). Numerous cross-country studies demonstrate a positive relationship between GDP and life expectancy, alongside lower overall mortality rates (Deaton, 2003). While higher GDP levels are generally associated with improved health infrastructure and access to medical care, several studies identify non-linear relationships between income and mortality, particularly for cardiovascular diseases (Sanmarchi et al., 2022). Wealthier countries generally have greater resources to allocate toward health systems, potentially improving disease prevention and treatment. However, empirical evidence suggests that economic prosperity alone does not guarantee better health outcomes. Despite EU-wide recommendations, participation rates in national screening programmes vary considerably between countries, reflecting differences in health system organization, public awareness, accessibility, and socioeconomic inequalities (OECD/European Commission, 2024). A large body of empirical literature examines the relationship between macroeconomic conditions and health outcomes, consistently demonstrating that macroeconomic environments play a significant role in shaping population health, influencing both access to healthcare services and overall health outcomes. However, evidence also suggests that increased healthcare spending does not always lead to proportional improvements in health outcomes. Studies highlight significant variation in efficiency across health systems, with some countries achieving better outcomes at lower levels of expenditure (Cylus et al., 2016). This suggests that the allocation and management of healthcare resources, rather than expenditure alone, play a crucial role in determining mortality outcomes. To date, no systematic research has been conducted on the association between GDP and participation in national cancer screening programmes in all EU countries (one of the crucial identified gaps), especially with business-related recommendations provided.

CHAPTER III: METHODOLOGY

3.1 Overview of the Research Problem

State healthcare funding in the EU comes from two main sources: national governments and EU-level initiatives. The healthcare and business relationship involves applying business practices like financial management and operational efficiency to healthcare organizations, which is vital for delivering quality care and ensuring financial sustainability. While healthcare is fundamentally about patient well-being, its structure involves complex markets, government intervention, and the need for business-minded approaches to manage costs, improve services, and foster innovation through entrepreneurship and strategic partnerships. Especially from the business perspective, to date, no systematic research has been conducted on the association of GDP, national healthcare expenditure and participation in national cancer screening programmes with mortality from cancer and cardiovascular diseases in the EU countries so that would be the main contribution of this study, which may serve as one of the potential directions for both healthcare and business benefit of the EU countries.

3.2 Research Purpose and Questions

While GDP has a well-established relation to healthcare quality and access, its impact on the effectiveness of national cancer screening programmes and mortality from cardiovascular diseases requires further research. This study aims to explore the dynamic relationship between GDP, national healthcare expenditure, participation in national cancer screening programmes and mortality of cardiovascular diseases in EU countries.

By analyzing these factors in a comparative context, we can identify patterns and correlations that might give a lot of information for future health policies and economic strategies for improving public healthcare and health outcomes in the EU countries as well as to identify some business-related opportunities among the extensive healthcare industry. The focus of this research is a comprehensive study on the association of GDP, national healthcare expenditure and participation in national cancer screening programmes with mortality from cancer and cardiovascular diseases in the EU countries.

The objectives of the study are:

1. To determine the association between GDP and participation in the national cancer screening programmes in EU countries.
2. To determine the association between GDP and mortality of cardiovascular diseases in EU countries.
3. To determine the association between participation in the national cancer screening programmes and mortality of related illnesses in EU countries.
4. To determine the association between the national healthcare expenditure and mortality of cardiovascular diseases in EU countries.
5. To determine the association between the national healthcare expenditure and cancer mortality in EU countries.
6. To determine the association between GDP, participation in the national cancer screening programmes and cancer mortality in EU countries.
7. To determine the association between the national healthcare expenditure, participation in the national cancer screening programmes and cancer mortality in EU countries.
8. To provide business-related recommendations for the healthcare industry in this particular domain.

3.3 Research Design

This is a mix-method (quantitative and qualitative) research, based on relevant open-source secondary data.

3.4 Population and Sample

The sample involved variables gathered from the relevant open-source databases (Eurostat, WHO, OECD and national health agencies). Sample is consisting of the following (27) EU countries: Austria, Belgium, Bulgaria, Croatia, Cyprus, Czechia, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden.

3.5 Instrumentation

Table 1. Dataset of variables for the EU countries (author's creation by open-source secondary data gathered from Eurostat, WHO, OECD and national health agencies)

COUNTRY	BC per 100 000	CEC per 100 000	COC per 100 000	BC SC (%)	CEC SC (%)	COC SC (%)	CVD MOR per 100 000	GDP (EUR BILLION)	HC EXPEN IN % OF GDP
Austria	17.1	2.8	21.1	40.1	NA	NA	346.6	449.4	11.2
Belgium	17.8	2.8	20.8	58	56.2	50.9	221.6	552.4	10.8
Bulgaria	16.6	8	33.7	NA	NA	NA	1074.3	84.5	7.9
Croatia	15.2	6.1	48.2	62	NA	25.5	591.7	61.1	7.2
Cyprus	15.2	2.5	16.4	29.8	NA	NA	257.8	27	8.1
Czechia	16.9	5	32.4	60.3	74.7	30	505.5	321	8.4
Denmark	17.8	2.9	27.7	83.3	60.7	59.5	210.8	381	9.5
Estonia	16.8	7.9	32.2	64.5	64	60.4	575.0	36.3	7.5
Finland	13.9	2	22	81.5	73	74.4	310.2	266	10.5
France	17.5	2.3	22.5	46.7	55.8	34.4	171.6	2653	11.5
Germany	19.7	3.7	24.0	52	47	NA	361.5	3953.9	11.7
Greece	16.2	2.6	21.5	14.5	NA	NA	324.6	208	8.4
Hungary	22.2	7.9	50.4	47.7	34.6	9	732.1	168	6.4
Ireland	18.9	3.5	25.5	69.3	74	48	266.5	506.3	6.6
Italy	17.3	1.6	24.2	55.4	41.5	34.9	270.3	1998	8.4
Latvia	20.7	11.1	31.6	36.1	55.2	25.8	806.2	36.1	7.3
Lithuania	18.8	11.3	30.4	59.7	60.3	56.5	784.5	67.4	7.3
Luxembourg	19.3	1.2	21.3	54.9	61.6	24.6	220.3	77.5	5.7
Malta	18.6	2.4	27.2	51.1	15.3	53.1	273.8	16.8	8.8
Netherlands	17.9	2.5	25.7	70.2	49.7	67.2	225.7	994	9.8
Poland	19.1	7.2	34.4	37.3	10.9	NA	489.6	749	7.1
Portugal	15.2	3.3	27.9	NA	NA	NA	237.9	242.3	10
Romania	17.1	13.1	33.7	NA	6.2	NA	924.5	286.4	5.7
Slovakia	21.7	7.9	39	42.7	66.5	48.9	627.8	110	7.4
Slovenia	19.7	3.1	27.6	77.5	74.4	60.8	332.9	52.2	9.3
Spain	12.6	2.7	28.7	68.9	NA	43	213.9	1373.6	9.2
Sweden	12.9	2.9	25.6	83	77.7	64.7	258.7	558	11.2

Following variables were used: Mortality from breast cancer, cervical cancer and colorectal cancer in the EU countries per 100 000 people; Participation in national cancer screening programmes of the EU countries for breast cancer, cervical cancer and colorectal cancer, Total mortality from cardiovascular diseases in the EU countries per 100 000 people; GDP of the EU countries; National healthcare expenditure in the percentage of total GDP of the EU countries.

3.6 Data Collection Procedures

Data was gathered from relevant open-source databases (Eurostat, WHO, OECD and national health agencies), based on recently available facts.

3.7 Data Analysis

For the statistical analysis (in order to examine the objectives 1-5) a correlation analysis was used. To examine the objectives 6-7 there a multiple regression analysis was used. Before running correlation analysis, Shapiro-Wilk test for normality of distribution was conducted for each variable. The objective 8 is fulfilled by qualitative method in combination of existing literature with personal expert opinion based on the results derived from the objectives 1-7.

3.8 Research Design Limitations

This study has several limitations: cross-sectional design while the analysis relies on a single point in time, limiting causal inference; use of country-level data does not account for individual-level factors or within-country variability; covariates such as stage at diagnosis, treatment uptake, and genetic factors were unavailable. Limitations are reflected in the fact that data for each required variable was not available, therefore the most recent data from relevant databases were used.

3.9 Conclusion

A mix-method (quantitative and qualitative) research, based on relevant open-source secondary data was conducted, including proper statistical methods, to fulfill set objectives.

CHAPTER IV: RESULTS AND DISCUSSION

4.1 Normality of distribution tests

In order to choose the most appropriate statistical analyses, the primary precondition of testing the normality of distribution of all the used variables was done.

Table 2. Normality of distribution test: Shapiro-Wilk test for the variable *Breast cancer mortality*

Parameter	Value
P-value	0.8202
W	0.9782
Sample size (n)	27
Average ($\bar{x}$)	17.5074
Median	17.5
Sample Standard Deviation (S)	2.3887
Sum of Squares	148.3585
b	12.0469
Skewness	-0.173
Skewness Shape	 Potentially Symmetrical (pval=0.699)
Excess kurtosis	-0.01948
Kurtosis Shape	 Potentially Mesokurtic , normal like tails (pval=0.982)

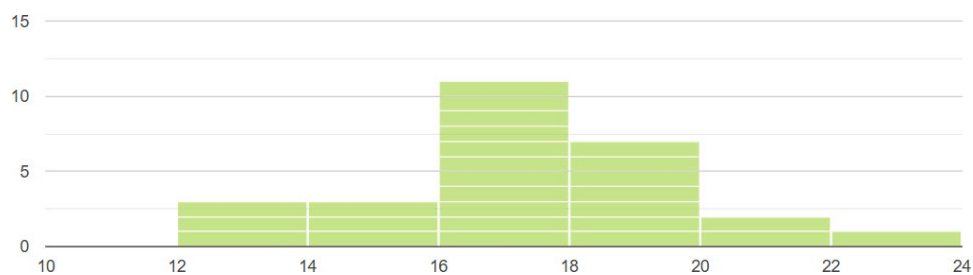


Figure 8. Histogram on the normality of distribution of the variable *Breast cancer mortality*

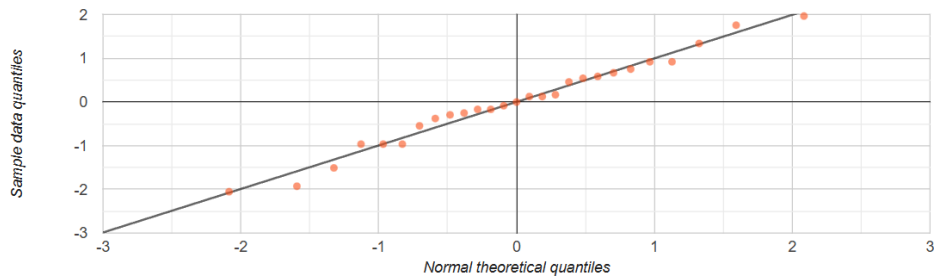


Figure 9. Quantile-Quantile Plot on the normality of distribution variable *Breast cancer mortality*

The Shapiro-Wilk test did not show a significant departure from normality, $W(27) = 0.98$, $p = 0.820$, so distribution is considered as normal.

Table 3. Normality of distribution test: Shapiro-Wilk test for the variable *Cervical cancer mortality*

Parameter	Value
P-value	0.0004194
W	0.8271
Sample size (n)	27
Average ($\bar{x}$)	4.8259
Median	3.1
Sample Standard Deviation (S)	3.3022
Sum of Squares	283.5119
b	15.3133
Skewness	1.149
Skewness Shape	 Asymmetrical, right/positive (pval=0.01)
Excess kurtosis	0.2885
Kurtosis Shape	 Potentially Mesokurtic, normal like tails (pval=0.741)

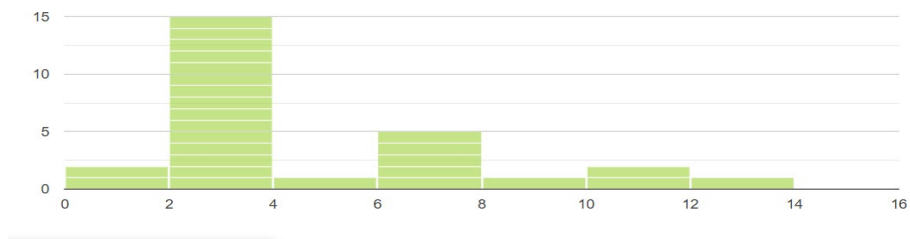


Figure 10. Histogram on the normality of distribution of the variable *Cervical cancer mortality*

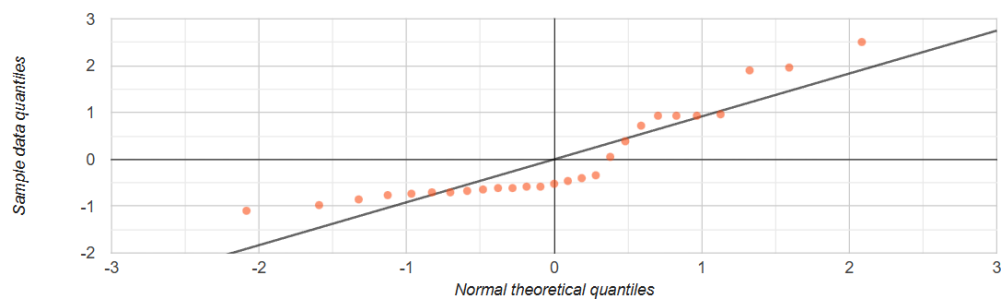


Figure 11. Quantile-Quantile Plot on the normality of distribution variable *Cervical cancer mortality*

The Shapiro-Wilk test showed a significant departure from normality, $W(27) = 0.83$, $p < 0.001$.

Table 4. Normality of distribution test: Shapiro-Wilk test for the variable *Colorectal cancer mortality*

Parameter	Value
P-value	0.01295
W	0.8994
Sample size (n)	27
Average ($\bar{x}$)	28.7296
Median	27.6
Sample Standard Deviation (S)	7.8804
Sum of Squares	1614.6163
b	38.1074
Skewness	1.2511
Skewness Shape	 Asymmetrical , right/positive (pval=0.005)
Excess kurtosis	1.8857
Kurtosis Shape	 Leptokurtic , long heavy tails (pval=0.031)

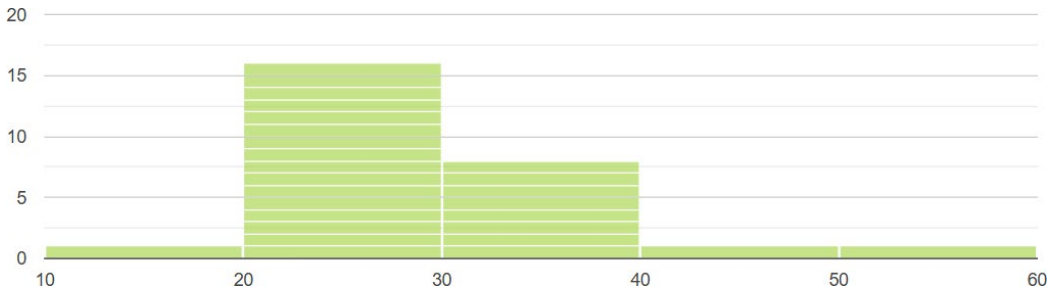


Figure 12. Histogram on the normality of distribution of the variable *Colorectal cancer mortality*

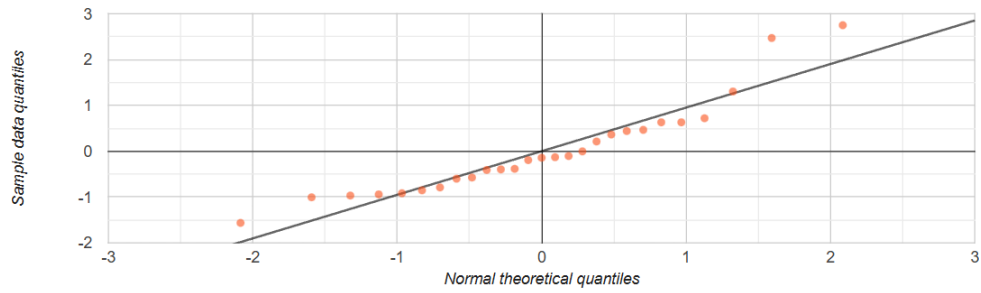


Figure 13. Quantile-Quantile Plot on the normality of distribution variable *Colorectal cancer mortality*

The Shapiro-Wilk test showed a significant departure from normality, $W(27) = 0.9$, $p = 0.013$.

Table 5. Normality of distribution test: Shapiro-Wilk test for the variable *Participation in breast cancer screening test*

Parameter	Value
P-value	0.8024
W	0.9756
Sample size (n)	24
Average ($\bar{x}$)	56.1042
Median	56.7
Sample Standard Deviation (S)	17.5164
Sum of Squares	7056.9496
b	82.9731
Skewness	-0.3454
Skewness Shape	 Potentially Symmetrical (pval=0.465)
Excess kurtosis	-0.03383
Kurtosis Shape	 Potentially Mesokurtic , normal like tails (pval=0.971)

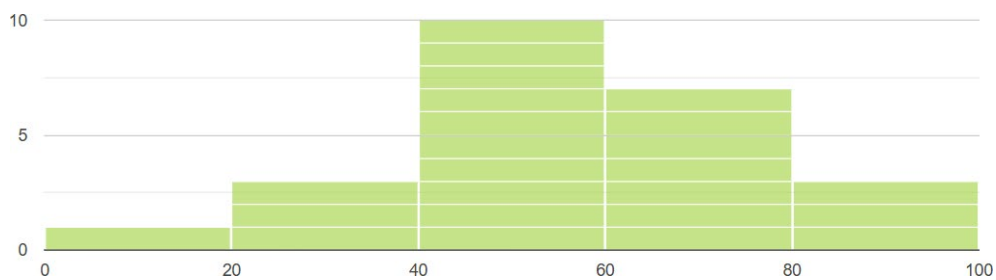


Figure 14. Histogram on the normality of distribution of the variable *Participation in breast cancer screening test*

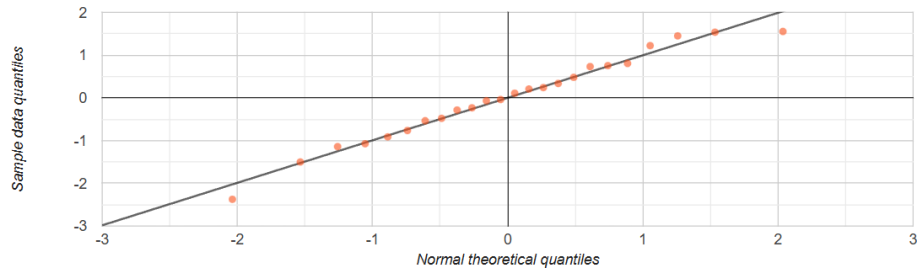


Figure 15. Quantile-Quantile Plot on the normality of distribution variable *Participation in breast cancer screening test*

The Shapiro-Wilk test did not show a significant departure from normality, $W(24) = 0.98$, $p = 0.802$.

Table 6. Normality of distribution test: Shapiro-Wilk test for the variable *Participation in cervical cancer screening test*

Parameter	Value
P-value	0.01522
W	0.8763
Sample size (n)	20
Average ($\bar{x}$)	52.965
Median	58.25
Sample Standard Deviation (S)	21.5141
Sum of Squares	8794.2655
b	87.7883
Skewness	-1.0576
Skewness Shape	 Asymmetrical , left/negative (pval=0.039)
Excess kurtosis	0.266
Kurtosis Shape	 Potentially Mesokurtic , normal like tails (pval=0.789)

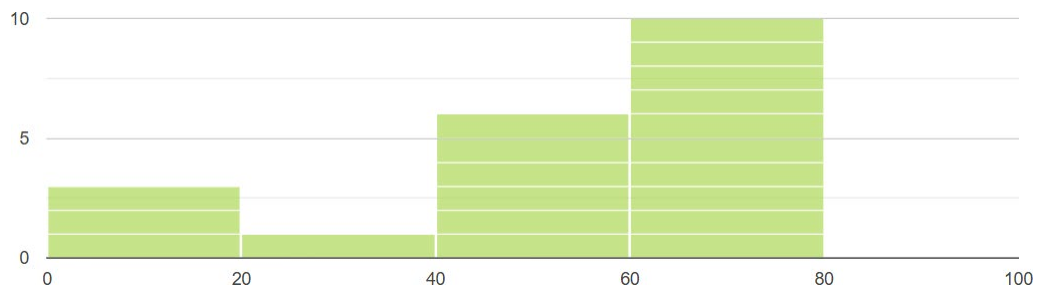


Figure 16. Histogram on the normality of distribution of the variable *Participation in cervical cancer screening test*

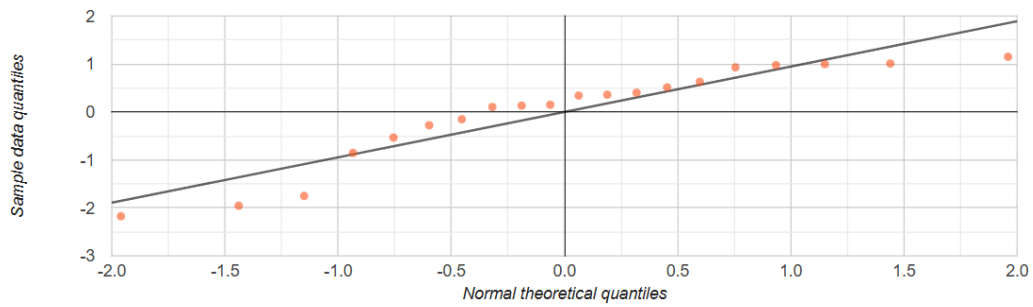


Figure 17. Quantile-Quantile Plot on the normality of distribution variable *Participation in cervical cancer screening test*

The Shapiro-Wilk test showed a significant departure from normality, $W(20) = 0.88$, $p = 0.015$.

Table 7. Normality of distribution test: Shapiro-Wilk test for the variable *Participation in colorectal cancer screening test*

Parameter	Value
P-value	0.6283
W	0.9628
Sample size (n)	19
Average ($\bar{x}$)	45.8737
Median	48.9
Sample Standard Deviation (S)	17.6212
Sum of Squares	5589.1368
b	73.3562
Skewness	-0.3735
Skewness Shape	 Potentially Symmetrical (pval=0.476)
Excess kurtosis	-0.6569
Kurtosis Shape	 Potentially Mesokurtic , normal like tails (pval=0.517)

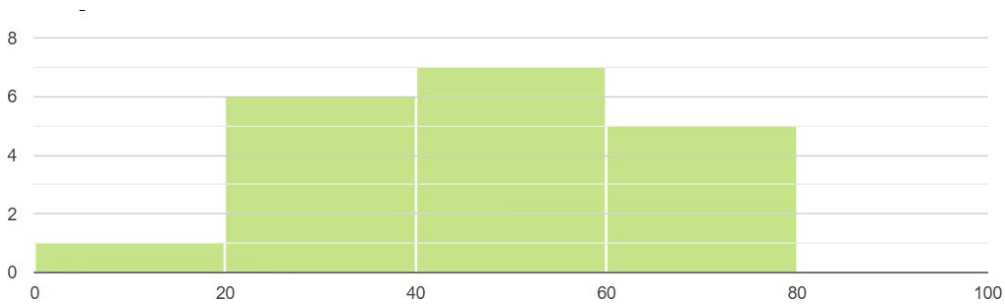


Figure 18. Histogram on the normality of distribution of the variable *Participation in colorectal cancer screening test*

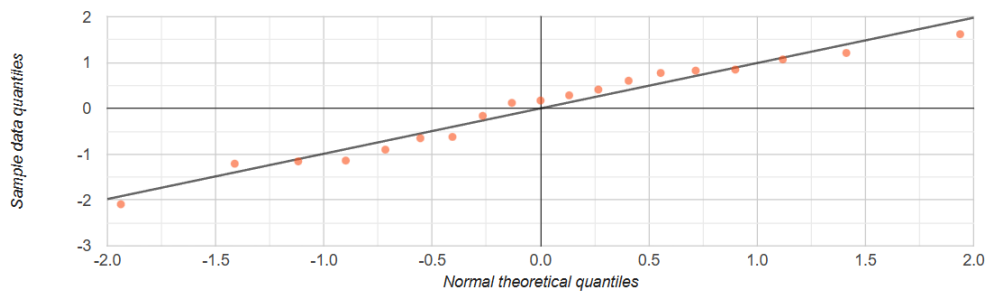


Figure 19. Quantile-Quantile Plot on the normality of distribution variable *Participation in colorectal cancer screening test*

The Shapiro-Wilk test did not show a significant departure from normality, $W(19) = 0.96$, $p = 0.628$.

Table 8. Normality of distribution test: Shapiro-Wilk test for the variable *Cardiovascular disease mortality*

Parameter	Value
P-value	0.0007806
W	0.8414
Sample size (n)	27
Average ($\bar{x}$)	430.2185
Median	324.6
Sample Standard Deviation (S)	249.8765
Sum of Squares	1623394.3807
b	1168.6985
Skewness	1.1434
Skewness Shape	 Asymmetrical, right/positive (pval=0.011)
Excess kurtosis	0.3326
Kurtosis Shape	 Potentially Mesokurtic, normal like tails (pval=0.703)

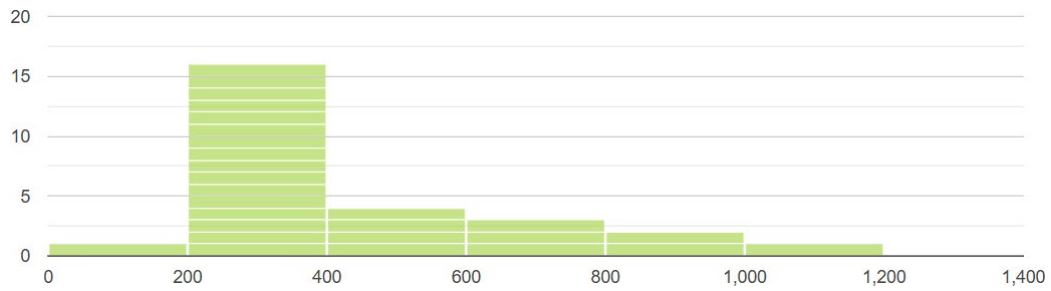


Figure 20. Histogram on the normality of distribution of the variable *Cardiovascular disease mortality*

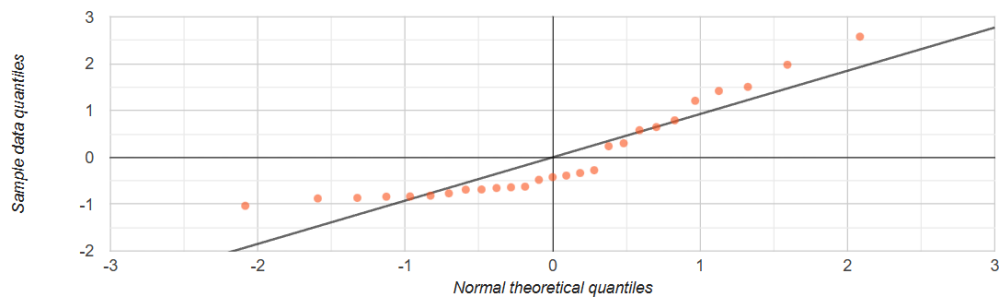


Figure 21. Quantile-Quantile Plot on the normality of distribution variable *Cardiovascular disease mortality*

The Shapiro-Wilk test showed a significant departure from normality, $W(27) = 0.84$, $p < 0.001$.

Table 9. Normality of distribution test: Shapiro-Wilk test for the variable *GDP* (in EUR billion)

W	0.6486
Sample size (n)	27
Average ($\bar{x}$)	601.0815
Median	266
Sample Standard Deviation (S)	919.6644
Sum of Squares	21990350.1007
b	3776.6271
Skewness	2.5453
Skewness Shape	 Asymmetrical , right/positive (pval=0)
Excess kurtosis	6.7332
Kurtosis Shape	 Leptokurtic , long heavy tails (pval=0)
Outliers	2653, 3953.9, 1998, 1373.6

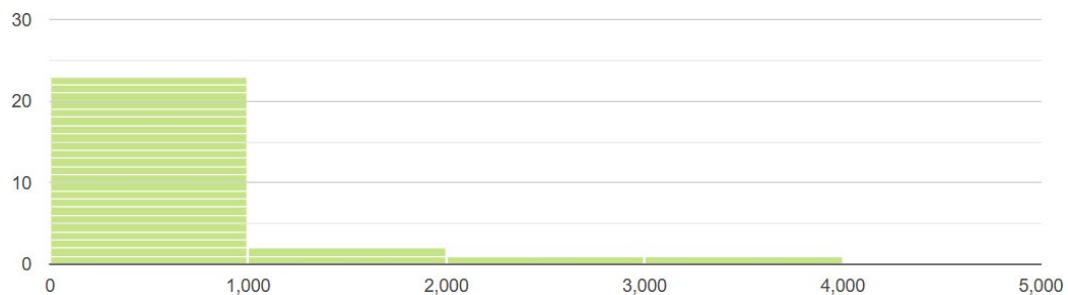


Figure 22. Histogram on the normality of distribution of the variable *GDP* (in EUR billion)

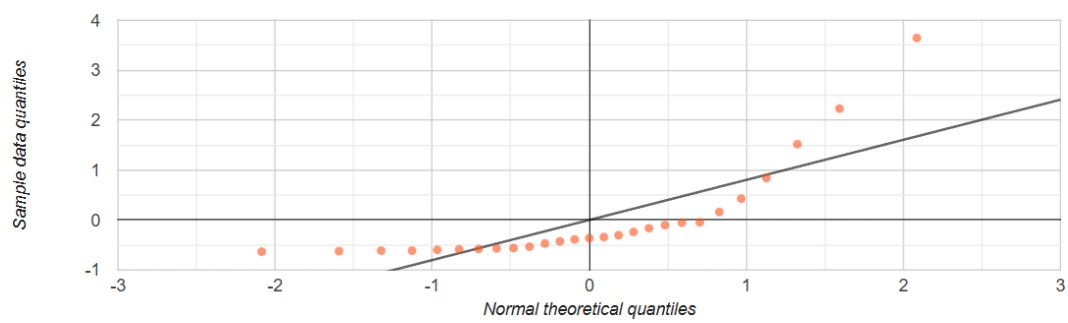


Figure 23. Quantile-Quantile Plot on the normality of distribution variable *GDP* (in EUR billion)

The Shapiro-Wilk test showed a significant departure from normality, $W(27) = 0.65$, $p < 0.001$.

Table 10. Normality of distribution test: Shapiro-Wilk test for the variable *Expenditure in healthcare by % of GDP*

Parameter	Value
P-value	0.2906
W	0.9555
Sample size (n)	27
Average ($\bar{x}$)	8.6259
Median	8.4
Sample Standard Deviation (S)	1.7741
Sum of Squares	81.8319
b	8.8425
Skewness	0.1841
Skewness Shape	 Potentially Symmetrical (pval=0.681)
Excess kurtosis	-0.9617
Kurtosis Shape	 Potentially Mesokurtic , normal like tails (pval=0.27)

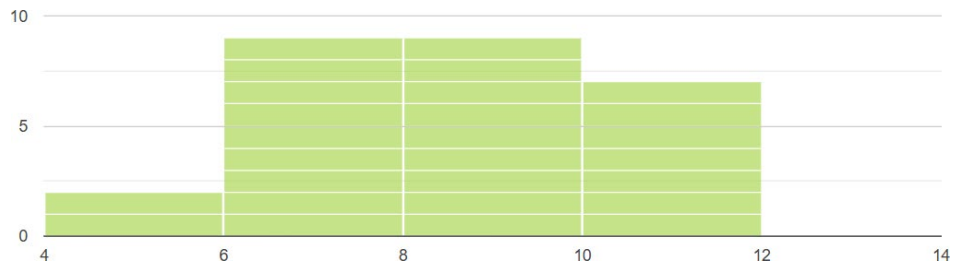


Figure 24. Histogram on the normality of distribution of the variable *Expenditure in healthcare by % of GDP*

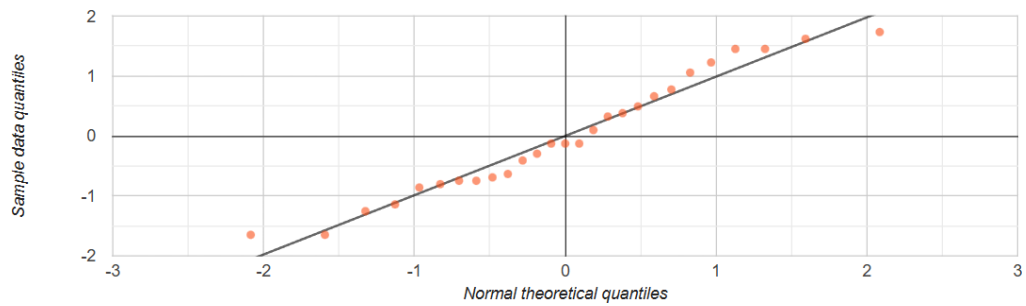


Figure 25. Quantile-Quantile Plot on the normality of distribution variable *Expenditure in healthcare by % of GDP*

The Shapiro-Wilk test did not show a significant departure from normality, $W(27) = 0.96$, $p = 0.291$.

4.2 Participation in breast cancer screening test and Breast cancer mortality

Breast cancer remains a leading cause of cancer-related mortality among women worldwide, including European Union (EU) countries (DeSantis et al., 2019; WHO, 2024). Early detection through organized screening programs has been recognized as a critical strategy for reducing mortality by facilitating timely diagnosis and treatment (IARC, 2016; European Commission, 2017). Despite widespread implementation of population-based mammography screening in many EU countries, participation rates and mortality outcomes vary significantly across member states (Eurostat, 2023; OECD/European Union, 2022). Understanding the relationship between participation in screening programs and mortality is essential to guide policy, optimize resource allocation, and improve the effectiveness of screening programmes.

Table 11. Pearson’s correlation analysis for testing the relationship between *Participation in breast cancer screening test* and *Breast cancer mortality*

Parameter	Value
Pearson correlation coefficient (r)	-0.3009
r ²	0.09054
P-value	0.1531
Covariance	-13.0733
Sample size (n)	24
Statistic	-1.48

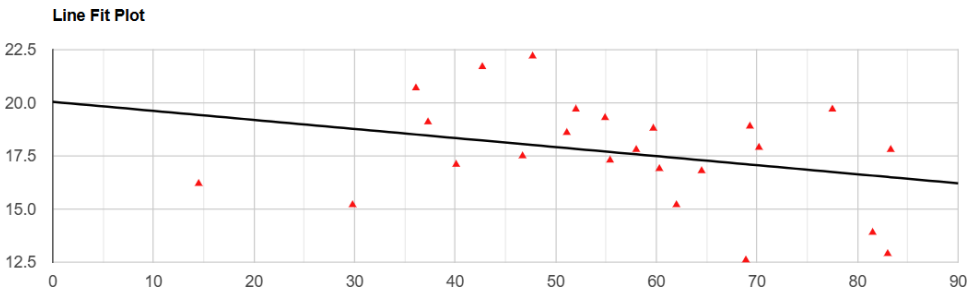


Figure 26. Line Fit Plot for testing the relationship between *Participation in breast cancer screening test* and *Breast cancer mortality*

Results of the Pearson correlation indicated that there is a non-significant medium negative relationship between X and Y, ($r(22) = 0.301$, $p = 0.153$). To investigate this relationship, Pearson's correlation analysis was conducted to assess the association between national-level participation rates in breast cancer screening programs and breast cancer mortality across 24 EU member states for which complete data were available. Pearson's correlation was employed to quantify the linear relationship between national screening participation and breast cancer mortality. The analysis indicated a negative correlation ($r = -0.301$), suggesting that countries with higher screening participation tended to have lower mortality rates. This finding is consistent with the theoretical and empirical understanding that population-based screening programs facilitate earlier detection of breast cancer, thereby improving treatment outcomes and survival (Tabár et al., 2011). However, this correlation did not reach statistical significance at the 0.05 level ($p = 0.153$). The coefficient of determination ($r^2 = 0.091$) implies that approximately 9.1% of the variability in breast cancer mortality could be explained by screening participation alone. The negative correlation observed aligns with theoretical expectations that participation in breast cancer screening programs may reduce mortality by enabling early detection and intervention (Tabár et al., 2011; IARC, 2016). The moderate magnitude of the correlation ($r = -0.301$) suggests that, while screening may contribute to mortality reduction, other factors also strongly influence outcomes.

The non-significant p-value indicates that, in this dataset, we cannot conclusively demonstrate a statistically robust association between screening participation and mortality. Several factors may account for this observation:

1. Heterogeneity across EU member states: Differences in program implementation, population demographics, follow-up care, and quality assurance contribute to variability in the effectiveness of screening programs (European Commission, 2017; OECD/European Union, 2022).
2. Influence of Confounding Factors: Breast cancer mortality is affected by treatment availability, stage at diagnosis, genetic predisposition, socio-economic status, and health system efficiency, which were not controlled in this bivariate analysis (Autier et al., 2010; DeSantis et al., 2019).
3. Sample size and Statistical Power: With 24 observations (member states), the analysis may have insufficient power to detect a significant effect, increasing the risk of Type II error.

The observed trend of a negative association between screening participation and breast cancer mortality is consistent with prior European studies. For example, the Swedish two-county trial demonstrated substantial reductions in mortality over 30 years of mammography screening (Tabár et al., 2011). Systematic reviews indicate that organized, population-based screening contributes to reduced mortality but emphasize that high participation rates alone are insufficient; program quality and timely follow-up are also critical (IARC, 2016; Independent UK Panel on Breast Cancer Screening, 2012).

More recent EU-focused studies support these findings. Eurostat data show that countries with participation rates exceeding 75% generally exhibit lower breast cancer mortality, while countries with lower uptake have comparatively higher mortality (Eurostat, 2023). However, exceptions exist, suggesting the influence of other structural and healthcare-related factors (OECD/European Union, 2022; European Cancer Organisation, 2023).

There are some selected EU country case examples discussed below. These examples illustrate how screening participation interacts with broader health system characteristics to shape mortality outcomes (Tabár et al., 2011).

1. High participation, low mortality: Nordic countries

Nordic EU countries such as Sweden, Finland, and Denmark are characterized by long-standing, well-organized population-based screening programmes with participation rates consistently exceeding 80%. These countries also report comparatively low breast cancer mortality rates. The Swedish two-county trial, one of the most influential studies in breast cancer screening research, demonstrated sustained mortality reductions over three decades of follow-up. The Nordic experience suggests that high participation combined with strong quality assurance, centralized cancer registries, and rapid access to treatment can translate screening uptake into measurable mortality reductions. These countries tend to fall below the regression line in Figure 26, reinforcing the notion that effective programme implementation amplifies the benefits of screening.

2. Moderate participation, moderate mortality: Western Europe countries such as France, Germany, and Belgium exhibit moderate-to-high screening participation rates but display more variable mortality outcomes. In these contexts, organized screening programmes coexist with opportunistic screening, leading to heterogeneity in coverage and follow-up. While mortality rates are generally lower than the EU average, they do not consistently match those observed in the Nordic countries. These countries tend to cluster around the centre of the scatter plot, highlighting that participation alone does not fully capture programme effectiveness. Variations in screening quality, diagnostic pathways, and treatment timeliness likely contribute to the observed outcomes.
3. Low participation, higher mortality: Eastern and Southern EU Countries
Several Eastern and Southern EU countries, including Romania, Bulgaria, and parts of Southern Europe, report lower screening participation rates and comparatively higher breast cancer mortality. These countries frequently appear above the regression line, indicating worse mortality outcomes than would be predicted based on participation rates alone. Lower participation in these contexts is often associated with limited programme coverage, lower public awareness, and barriers to access such as geographic distance or workforce shortages. Additionally, later stage at diagnosis and constrained access to specialized oncology services exacerbate mortality risks. These cases underscore the compounded effect of low screening uptake and broader health system limitations.

Although the correlation was not statistically significant, the observed negative trend has meaningful policy implications. Increasing participation in organized breast cancer screening could contribute to mortality reduction, particularly when integrated with quality control measures and equitable access to treatment. Policies should focus on:

1. Increasing participation rates: Targeting underserved populations through public awareness campaigns, invitations, and reminders (European Commission, 2017; Eurostat, 2023).
2. Improving program quality: Ensuring adherence to EU screening guidelines, standardized image interpretation, and timely diagnostic follow-up (IARC, 2016; ESMO, 2024).
3. Integrating screening with comprehensive cancer control: Combining early detection with effective treatment pathways, survivorship programs, and outcome monitoring (European Cancer Organisation, 2023; WHO, 2024).

Such strategies may enhance the effectiveness of screening programs and maximize their impact on breast cancer mortality reduction across the EU. In summary, Pearson's correlation analysis indicates a negative but non-significant association between breast cancer screening participation and mortality across EU countries. The results are consistent with prior evidence suggesting that organized screening can reduce mortality, though screening participation alone accounts for only a modest proportion of observed variability. Policy implications include the need to enhance program participation, ensure high-quality implementation, and integrate screening with comprehensive cancer care strategies. Further research employing longitudinal and multivariable approaches is warranted to better understand the independent contribution of screening participation to mortality reduction in the EU.

4.3 Participation in cervical cancer screening test and Cervical cancer mortality

Table 12. Spearman's correlation analysis for testing the relationship between *Participation in cervical cancer screening test* and *Cervical cancer mortality*

Parameter	Value
Spearman's rank correlation coefficient (r_s)	-0.1266
r^2	0.01602
P-value	0.595
Covariance	-4.4211
Sample size (n)	20
Statistic	-0.5413

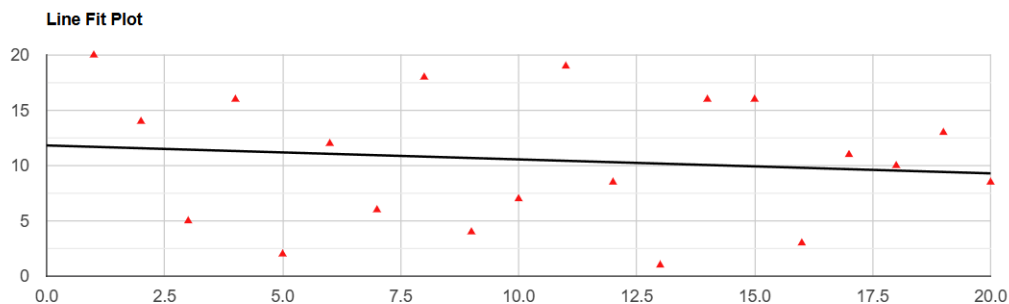


Figure 27. Line Fit Plot for testing the relationship between *Participation in cervical cancer screening test* and *Cervical cancer mortality*

Results of the Spearman correlation indicated that there is a non-significant small negative relationship between X and Y, ($r(18) = 0.127$, $p = 0.595$). A total of 20 EU countries ($n = 20$) were included in the final dataset, reflecting aggregated population-level indicators. Given the small sample size and the potential non-normal distribution of variables, Spearman's rank correlation coefficient (ρ) was selected as the most appropriate statistical measure to assess the monotonic relationship between screening participation and mortality outcomes. Visual inspection of the scatter plot (Figure 27) suggests a slight downward trend, indicating that higher screening participation may be associated with lower cervical cancer mortality. However, the dispersion of data points around the fitted line is substantial, with no clear linear or monotonic pattern apparent.

The Spearman's rank correlation coefficient between participation in cervical cancer screening and cervical cancer mortality was $\rho = -0.1266$, indicating a very weak negative correlation. This suggests that, within the observed data, increases in screening participation are associated with marginal decreases in mortality. However, the magnitude of this association is minimal. The coefficient of determination (r^2) was 0.016, indicating that approximately 1.6% of the variability in cervical cancer mortality can be explained by variation in screening participation alone. This value demonstrates that screening participation, as measured in this dataset, accounts for only a small fraction of the observed differences in mortality rates.

The correlation was not statistically significant ($p = 0.595$), exceeding the conventional alpha level of 0.05. The test statistic (-0.5413) further confirms the absence of a statistically meaningful monotonic association.

The absence of a statistically significant association between cervical cancer screening participation and mortality observed in this study contrasts with the well-established protective effect of organized screening programmes reported in the literature. One of the most important considerations in interpreting these findings is the small sample size ($n = 20$). With such a limited number of observations, even clinically meaningful associations may fail to reach statistical significance. The wide dispersion observed in the scatter plot further suggests heterogeneity within the data, which would dilute detectable correlations.

Despite the non-significant findings, the results should not be interpreted as contradicting the established evidence base. The effectiveness of cervical cancer screening has been firmly established in high-income countries through long-term observational studies and programme evaluations. The International Agency for Research on Cancer (2005) concluded that cytology-based screening reduces cervical cancer mortality by up to 80% in settings with organised, high-quality programmes. These findings were derived from large population-based datasets with extended follow-up periods, allowing detection of long-term mortality reductions. Similarly, population studies from Nordic countries demonstrated marked declines in cervical cancer mortality following the introduction of systematic screening programmes. For example, long-term data from countries such as Finland and Sweden showed sustained mortality reductions attributable to organised cytology-based screening (Vaccarella et al., 2013). In contrast, opportunistic or poorly coordinated screening systems produced more modest and inconsistent benefits.

More recent evidence supports the superiority of HPV-based screening compared with cytology alone. A pooled analysis of randomised trials demonstrated that HPV testing provides greater protection against invasive cervical cancer than cytology, particularly over longer follow-up intervals. The protective effect becomes increasingly apparent after several years, reflecting the natural history of HPV-mediated carcinogenesis. Furthermore, global modelling analyses have projected that high-coverage HPV-based screening combined with vaccination could lead to cervical cancer elimination as a public health problem in many countries during the 21st century (Arbyn et al., 2020). These projections assume sustained high participation rates and effective follow-up care. The present study does not differentiate between screening modalities (cytology vs HPV testing), nor does it account for programme quality or follow-up effectiveness. Therefore, it may underestimate the impact of contemporary screening approaches. The weak correlation observed could partly reflect heterogeneity in screening methods across the analysed observations. Ginsburg et al. (2017) emphasized that in low- and middle-income countries, limited treatment capacity and delayed follow-up substantially reduce the mortality impact of screening initiatives. Similarly, variations in socioeconomic status and healthcare access significantly influence cervical cancer outcomes independent of screening coverage (Vaccarella et al., 2013). The discrepancy between those findings and the present results underscores the importance of study design, scale, and analytical approach. Small, cross-sectional datasets are ill-suited to capturing complex, long-term public health effects.

From a policy perspective, these findings highlight the danger of evaluating screening programmes solely on the basis of short-term or cross-sectional mortality indicators. Policymakers should consider broader metrics, including incidence of advanced disease, stage at diagnosis, and long-term survival. For future research, the results underscore the need for: longitudinal datasets, larger sample sizes, multivariable modelling, and integration of screening, vaccination, and treatment indicators. Such approaches would provide a more comprehensive understanding of how screening participation interacts with broader health system factors to influence cervical cancer outcomes. In conclusion, the present analysis identified a weak, non-significant inverse association between participation in cervical cancer screening and cervical cancer mortality. While these findings do not demonstrate a statistically significant relationship, they are directionally consistent with the broader literature. The results highlight the methodological challenges of assessing screening effectiveness using small, cross-sectional datasets and reinforce the importance of longitudinal, system-level evaluations in cervical cancer control research.

4.4 Participation in colorectal cancer screening test and Colorectal cancer mortality

Colorectal cancer is a major health challenge globally and within EU. It is among the most diagnosed malignancies and remains a leading cause of cancer-related mortality across EU countries (Arnold et al., 2017). Despite advances in treatment and diagnostics, substantial cross-national variation persists in both incidence and mortality rates within EU. Colorectal cancer is widely regarded as one of the most preventable malignancies through organized screening interventions (Brenner et al., 2014). The effectiveness of screening, however, depends not only on test performance but also on participation rates, follow-up compliance, and healthcare system capacity.

Table 13. Spearman's correlation analysis for testing the relationship between *Participation in colorectal cancer screening test* and *Colorectal cancer mortality*

Parameter	Value
Spearman's rank correlation coefficient (r_s)	-0.2825
r^2	0.07978
P-value	0.2429
Covariance	-8.9444
Sample size (n)	19
Statistic	0.2825

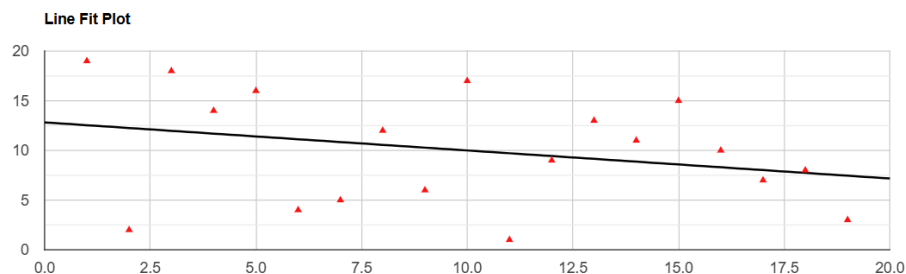


Figure 28. Line Fit Plot for testing the relationship between *Participation in colorectal cancer screening test* and *Colorectal cancer mortality*

Results of the Spearman correlation indicated that there is a non-significant small negative relationship between X and Y, ($r(17) = 0.282$, $p = 0.243$). The analysis demonstrated a weak inverse relationship (Spearman's $\rho = -0.2825$), indicating that countries with higher participation in screening tend to report lower colorectal cancer mortality rates. However, this association did not reach statistical significance ($p = 0.2429$), and screening participation explained approximately 7.98% of the variation in mortality.

Colorectal cancer screening can reduce mortality from colorectal cancer by early detection and treatment like removal of precancerous lesions. Some studies and randomized controlled trials have demonstrated significant reductions in colorectal cancer mortality following screening implementation (Atkin et al., 2010; Shaikat et al., 2013; Brenner et al., 2014). Therefore, although not statistically significant, the inverse trend observed across EU countries is consistent with the expected protective effect of screening.

Previous studies have shown that the use of colorectal cancer screening test reduces mortality from colorectal cancer by 15% - 33% (Mandel et al., 1993; Atkin et al., 2010; Shaikat et al., 2013). European comparative research indicates substantial variation in colorectal cancer mortality trends across countries, partly attributable to differences in screening implementation and healthcare system capacity (Arnold et al., 2017). Countries with organized, population-based screening programmes generally demonstrate more favorable mortality trends than those relying on opportunistic approaches. Higher participation in colorectal cancer screening is associated with lower mortality. However, the relationship is weak and not statistically significant in this analysis. The direction of association is consistent with extensive clinical and epidemiological evidence demonstrating the effectiveness of screening. The absence of statistical significance likely reflects methodological constraints, limited statistical power, and the multifactorial nature of colorectal cancer mortality.

4.5 GDP and Participation in breast cancer screening test

Table 14. Spearman's correlation analysis for testing the relationship between *GDP* and *Participation in breast cancer screening test*

Parameter	Value
Spearman's rank correlation coefficient (r_s)	0.1739
r^2	0.03025
P-value	0.4105
Covariance	8.6957
Sample size (n)	24
Statistic	0.1739

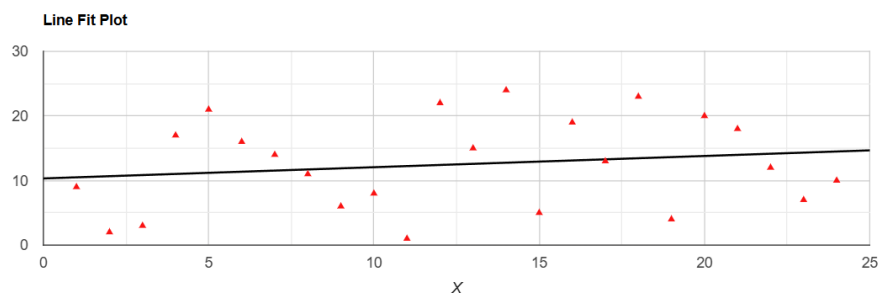


Figure 29. Line Fit Plot for testing the relationship between *GDP* and *Participation in breast cancer screening test*

Results of the Spearman correlation indicated that there is a non-significant small positive relationship between X and Y, ($r(22) = 0.174$, $p = 0.410$). A Spearman's rank-order correlation was conducted to examine the relationship between GDP and participation in breast cancer screening. The analysis indicated a weak positive association between the two variables. However, this relationship was not statistically significant, $r_s(22) = 0.17$, $p = 0.41$. The small correlation coefficient suggests that GDP accounts for minimal variation in screening participation rates ($r^2 = 0.03$). Therefore, there is no evidence of a statistically significant relationship between GDP and participation in breast cancer screening within the sample.

The findings revealed a weak positive but non-significant relationship between GDP and participation in breast cancer screening. Although countries with higher GDP tended to show slightly higher participation rates, the association was small and did not reach statistical significance. This suggests that economic prosperity alone may not be a strong determinant of screening uptake. A lack of statistical significance indicates that other factors, such as healthcare system organization, public health policies, accessibility of screening programs, education, cultural attitudes, or awareness campaigns, may play a more influential role in determining participation rates than GDP itself. Additionally, the relatively small sample size ($n = 24$) may have limited the statistical power to detect a meaningful association. Future research incorporating a larger sample and additional explanatory variables may provide a more comprehensive understanding of the factors influencing breast cancer screening participation.

A substantial body of research suggests that higher national income is associated with stronger health system capacity, greater healthcare expenditure, and improved access to preventive services. Global analyses such as those reported by WHO (2020) and the World Bank (2023) consistently demonstrate that high-income countries are more likely to implement organized, population-based cancer screening programs. Similarly, comparative health system evaluations by the OECD (2013) indicate that wealthier member states tend to achieve higher average screening coverage. This relationship is often explained through several mechanisms:

1. Greater fiscal capacity to finance nationwide screening programs
2. Stronger primary healthcare infrastructure
3. Higher levels of technological investment (e.g., mammography equipment)
4. Broader insurance coverage and reduced financial barriers

From this perspective, one might expect a statistically significant positive relationship between GDP and screening participation. However, it is crucial to note that much of this literature does not test GDP directly as a continuous predictor of screening participation. Instead, studies often compare high-income versus middle-income categories or examine healthcare expenditure as a percentage of GDP. This distinction is methodologically important. Income classification (e.g., high-income vs. low-income) captures structural thresholds in system development, whereas correlational analysis across a relatively homogeneous sample ($n = 24$ countries) may not yield the same pattern.

A growing body of literature argues that the organization of screening programs, rather than national wealth per se, is the key determinant of participation rates. Reports from the WHO (2020) emphasize that organized, invitation-based programs with centralized registries achieve significantly higher uptake than opportunistic systems, regardless of GDP. Another important dimension concerns internal socioeconomic inequalities. Research demonstrates that even in high-GDP countries, screening participation is stratified by education, income, ethnicity and geographic location. Cross-national analyses show that socioeconomic disparities persist across Europe despite overall economic prosperity (Palència et al., 2010). Theoretically, this reflects the argument advanced by Wilkinson and Pickett (2009) that relative inequality may exert stronger effects on health outcomes than aggregate wealth. GDP reflects total economic production but does not account for distribution. Consequently, two countries with similar GDP may demonstrate markedly different participation patterns depending on equity structures and social policy frameworks.

The present study's non-significant result may therefore reflect the limitations of aggregate GDP as an explanatory variable. If within-country inequalities exert stronger influence on individual screening behaviour than national wealth, macro-level correlations will appear weak.

Compared to previous literature, these findings are in line with existing knowledge. While macroeconomic theory predicts a positive relationship between GDP and screening participation, empirical evidence from this study shows that this relationship is weak and statistically insignificant. These results support a growing body of research that emphasizes institutional organization, equity and behavioral determinants more than economic size alone (OECD, 2013; WHO, 2020; Wilkinson and Pickett, 2009). GDP can enable the establishment of preventive services, but does not guarantee public engagement.

4.6 GDP and Participation in cervical cancer screening test

Cervical cancer is one of the most common types of cancer in women globally, particularly in low- and middle-income countries where it is the second leading cause of cancer death (HZJZ, 2022). Understanding the socioeconomic determinants of screening participation has been central to public health research. Among these determinants, national wealth, typically measured by GDP, has been hypothesized to influence access to preventive health services such as Pap smears and HPV testing, with higher GDP presumed to facilitate broader screening coverage through improved health infrastructure and resource allocation (World Bank, 2020).

Table 15. Spearman's correlation analysis for testing the relationship between *GDP* and *Participation in cervical cancer screening test*

Parameter	Value
Spearman's rank correlation coefficient (r_s)	-0.1534
r^2	0.02353
P-value	0.5349
Covariance	-5.3684
Sample size (n)	20
Statistic	0.1534

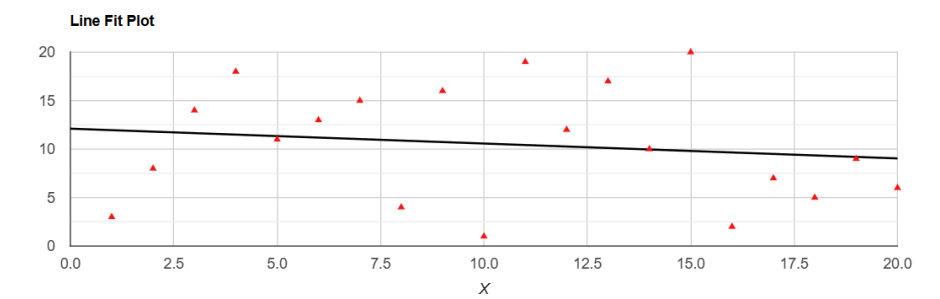


Figure 30. Line Fit Plot for testing the relationship between *GDP* and *Participation in cervical cancer screening test*

Results of the Spearman correlation indicated that there is a non-significant small negative relationship between X and Y, ($r(18) = 0.153$, $p = 0.535$). Spearman's rank-order correlation was conducted to examine the relationship between GDP and participation in cervical cancer screening. The analysis revealed a weak negative correlation between the two variables ($r_s = -0.1534$, $n = 20$). However, this association was not statistically significant ($p = 0.5349$), indicating that GDP was not significantly related to participation in cervical cancer screening within the study sample. The coefficient of determination ($r^2 = 0.0235$) further suggests that only approximately 2.35% of the variation in screening participation can be explained by differences in GDP. Overall, these findings indicate that GDP does not appear to be a meaningful predictor of participation in cervical cancer screening in the present study.

Research challenges the notion that GDP is a consistent predictor of screening uptake. This study supports results of previous research. Analysis of 20 countries revealed a weak negative correlation between GDP and cervical cancer screening participation ($r_s = -0.1534$, $p = 0.5349$), with an r^2 value of 0.0235.

Although the relationship was in the negative direction, it was not statistically significant, indicating that GDP accounted for only 2.35% of the variation in screening participation. These results suggest that, within this sample, higher national wealth does not reliably predict higher screening uptake.

The literature and the present findings suggest that economic development alone is insufficient to explain variation in cervical cancer screening participation. These results have important policy implications. Efforts to increase cervical cancer screening participation should prioritize strengthening organized screening programs, improving health literacy, reducing structural barriers and addressing inequities in access. Economic growth, in isolation, is unlikely to produce substantial improvements in screening coverage without deliberate policy action and targeted public health strategies. Future research should therefore adopt multi-level analytical frameworks that integrate macroeconomic indicators with health system variables and individual-level determinants to better understand the pathways influencing screening participation.

4.7 GDP and Participation in colorectal cancer screening test

Colorectal cancer is third most diagnosed cancer which diagnoses rapidly increases with age and in Western countries (Klimeck et al, 2023). It’s the second leading cause of cancer death worldwide (Li et al., 2025.)

Table 16. Spearman’s correlation analysis for testing the relationship between *GDP* and *Participation in colorectal cancer screening test*

Parameter	Value
Spearman's rank correlation coefficient (r_s)	0.04912
r^2	0.002413
P-value	0.6387
Covariance	1.5556
Sample size (n)	19
Statistic	0.04912

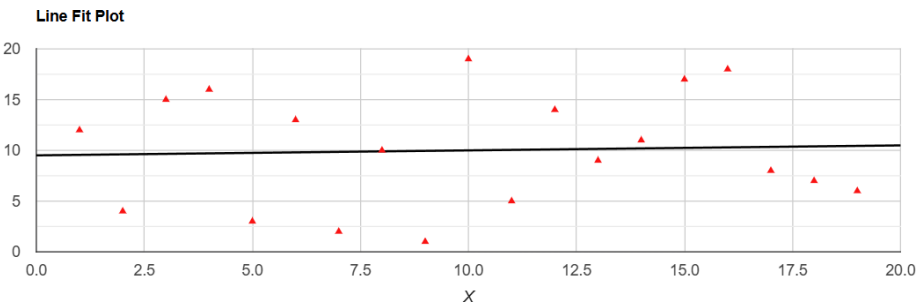


Figure 31. Line Fit Plot for testing the relationship between *GDP* and *Participation in colorectal cancer screening test*

Results of the Spearman correlation indicated that there is a non-significant very small positive relationship between X and Y, ($r(17) = 0.0491$, $p = 0.639$). Spearman's rank-order correlation was conducted to examine the relationship between GDP and participation in colorectal cancer screening across the sampled countries ($n = 19$). Spearman's correlation was selected due to the small sample size and the potential non-normal distribution of variables. Since the p-value exceeds the conventional alpha level of 0.05, the relationship is not statistically significant.

Visual inspection of the line fit plot further supports the statistical findings, as the data points appear widely dispersed with an almost flat trend line, indicating no meaningful directional relationship. Overall, the findings demonstrate that, within this sample, GDP is not significantly associated with participation in colorectal cancer screening programmes.

A substantial body of literature links national income to overall population health outcomes. The seminal work of Preston (1975) demonstrated a strong positive association between GDP per capita and life expectancy, giving rise to the so-called Preston Curve. Subsequent research has interpreted this relationship as evidence that economic development facilitates improvements in healthcare infrastructure, sanitation, education, and technological capacity. From this macroeconomic perspective, it would be reasonable to hypothesise that higher GDP countries should exhibit stronger preventive healthcare performance, including higher screening participation.

Colorectal cancer (CRC) screening is widely recognized as an effective strategy for reducing incidence and mortality through early detection and removal of precancerous lesions. However, participation rates in CRC screening programmes vary substantially both within and between countries. Although GDP per capita is often used as an indicator of national wealth and development, evidence suggests that GDP is not a direct determinant of screening uptake. Rather, GDP may act as a distal structural determinant, influencing health system capacity, organization of screening programmes, and broader socioeconomic conditions that shape individual health behaviours. Cross-national comparisons demonstrate that higher-income countries are more likely to implement organized, population-based CRC screening programmes (OECD, 2023; Schreuders et al., 2015). Organized programmes-characterised by systematic invitation, quality assurance, and follow-up protocols-are generally associated with higher participation rates compared with opportunistic screening systems (Schreuders et al., 2015). Consequently, countries with higher GDP often report higher overall screening coverage. However, national wealth alone does not guarantee equitable participation.

A literature indicates that socioeconomic position, including income, education, employment status, and area-level deprivation, is strongly associated with CRC screening participation. In the United Kingdom, von Wagner et al. (2011) found a pronounced socioeconomic gradient in uptake of faecal occult blood testing (FOBT) within the national screening programme. Participation declined significantly across deprivation quintiles despite the programme being universally available and free of charge. This finding suggests that financial barriers alone do not explain disparities; rather, structural and behavioural determinants are influential. Similarly, a large Danish cohort study demonstrated that individuals in higher income and education groups were significantly more likely to participate in CRC screening compared to those in lower socioeconomic groups (Larsen et al., 2017). Comparable socioeconomic inequalities have been reported across multiple European countries, even in settings with universal healthcare systems (de Klerk et al., 2018). These findings indicate that while GDP may enable implementation of organized screening infrastructure, inequalities in uptake persist within high-income countries. Globally, the OECD reports that CRC screening participation rates range widely from below 20% in some countries to above 65% in others, despite comparable levels of GDP per capita (OECD, 2023). This variation underscores the importance of programme organization, invitation systems, cultural attitudes, and healthcare accessibility in shaping uptake. In some middle-income countries, targeted public health campaigns and structured invitation systems have achieved participation rates comparable to high-income countries, demonstrating that effective policy design can mitigate the influence of macroeconomic constraints.

4.8 GDP and Cardiovascular disease mortality

To examine the relationship between economic development and cardiovascular health outcomes, a Spearman’s correlation analysis was conducted to assess the association between gross domestic product (GDP) and cardiovascular disease (CVD) mortality across the 27 European Union member states (n = 27).

Table 17. Spearman’s correlation analysis for testing the relationship between *GDP* and *Cardiovascular diseases mortality*

Parameter	Value
Spearman's rank correlation coefficient (r_s)	-0.4212
r^2	0.1774
P-value	0.03159
Covariance	-26.5385
Sample size (n)	27
Statistic	0.4212

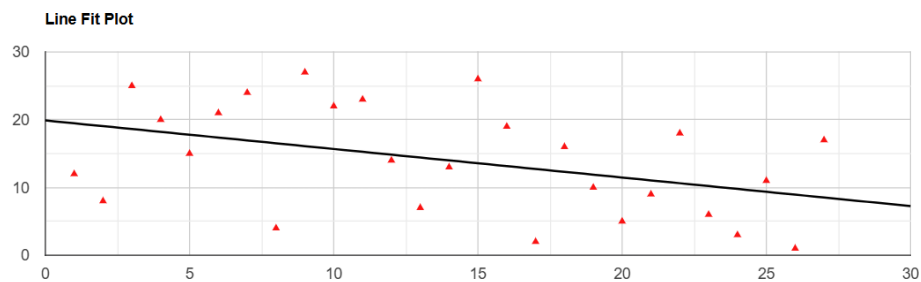


Figure 32. Line Fit Plot for testing the relationship between *GDP* and *Cardiovascular diseases mortality*

Results of the Spearman correlation indicated that there is a **significant medium negative relationship** between X and Y, ($r(25) = 0.421$, $p = 0.032$). The negative correlation coefficient indicates that higher GDP levels are associated with lower cardiovascular mortality rates. The p-value ($p < 0.05$) confirms that this relationship is statistically significant at the 5% significance level. The coefficient of determination ($r^2 = 0.177$) suggests that approximately 17.7% of the variability in cardiovascular mortality across EU countries can be explained by differences in GDP alone. The line fit plot (Figure 32) further illustrates the inverse relationship, indicating decreasing mortality rates with increasing GDP levels.

The observed moderate negative association aligns with established epidemiological evidence that higher national income levels are generally linked to improved health outcomes, including reduced cardiovascular mortality (Mackenbach et al., 2015; OECD/European Union, 2023). Higher GDP per capita often reflects stronger health systems, greater healthcare expenditure, improved access to preventive services, and broader social welfare protections. The study identified a statistically significant moderate negative association between gross domestic product (GDP) and cardiovascular disease mortality (Spearman's $r_s = -0.421$, $p = 0.032$, $n = 27$), indicating that higher levels of national income are associated with lower cardiovascular mortality across EU countries. The inverse association observed in the present study is strongly consistent with prior research. Comparative analyses from the Organization for Economic Co-operation and Development (OECD/European Union, 2023) demonstrate that higher-income EU countries generally exhibit lower age-standardized mortality rates from cardiovascular causes. Countries such as France, Germany and Netherlands consistently report lower CVD mortality compared to lower-GDP countries including Bulgaria and Romania (Eurostat, 2023). Similarly, findings from the Global Burden of Disease Study (GBD 2019 Collaborators, 2020) confirm that high-income European countries experienced earlier and steeper declines in cardiovascular mortality compared with countries undergoing economic transition in Central and Eastern Europe. Therefore, the direction of association in the present study corroborates established macro-level epidemiological patterns. Within the EU, economic heterogeneity remains substantial despite shared institutional frameworks.

Higher-income Western European member states benefit from:

- Greater healthcare expenditure per capita
- Advanced cardiac and stroke care infrastructure
- Higher uptake of preventive pharmacotherapy
- Stronger tobacco control and public health policies

In contrast, several Central and Eastern European member states face challenges including:

- Higher prevalence of hypertension and smoking
- Limited access to advanced cardiac interventions
- Underinvestment in preventive healthcare
- Socioeconomic instability following political transition

However, it is important to note that GDP does not fully capture structural inequality. Some high-income countries still exhibit substantial internal socioeconomic gradients in cardiovascular mortality. Therefore, while GDP correlates with national-level mortality patterns, it does not eliminate intra-country disparities.

4.9 GDP and Breast cancer mortality

To examine the association between gross domestic product (GDP) and breast cancer mortality, a Spearman's rank-order correlation analysis was conducted using data from 27 observations. Spearman's correlation was selected due to its suitability for assessing monotonic relationships without assuming normal distribution of the variables.

Table 18. Spearman's correlation analysis for testing the relationship between *GDP* and *Breast cancer mortality*

Parameter	Value
Spearman's rank correlation coefficient (r_s)	-0.08617
r^2	0.007426
P-value	0.6691
Covariance	-5.4231
Sample size (n)	27
Statistic	-0.4325

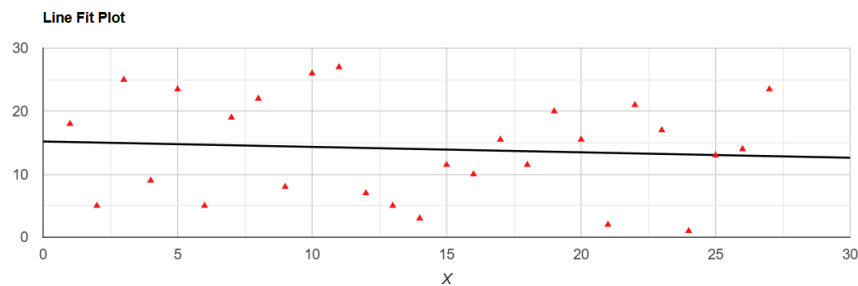


Figure 33. Line Fit Plot for testing the relationship between *GDP* and *Breast cancer mortality*

Results of the Spearman correlation indicated that there is a non-significant very small negative relationship between X and Y, ($r(25) = 0.0862$, $p = 0.669$). The analysis yielded a Spearman's correlation coefficient of $r_s = -0.086$, indicating a very weak negative association between GDP and breast cancer mortality. The negative direction suggests that higher GDP levels are marginally associated with lower breast cancer mortality rates. However, the magnitude of the coefficient indicates that this relationship is negligible in practical terms. The coefficient of determination ($r^2 = 0.0074$) indicates that approximately 0.74% of the variability in breast cancer mortality can be explained by GDP. This proportion of explained variance is extremely small and suggests minimal predictive value.

The correlation was not statistically significant ($p = 0.669$). The test statistic (-0.4325) further supports the absence of a statistically meaningful relationship. Visual inspection of the line fit plot corroborates the statistical findings, showing widely dispersed data points and a nearly horizontal regression line with a slight negative slope. In summary, the findings indicate that GDP is not significantly associated with breast cancer mortality within the sampled population. The results suggest that macroeconomic status, as measured by GDP, does not independently explain variations in breast cancer mortality rates in this dataset.

The findings indicate that GDP is not significantly associated with breast cancer mortality within the sampled population. Although the direction of the relationship is negative, suggesting that higher economic development may be linked to slightly lower mortality, the strength of the association is extremely weak and statistically insignificant. Global epidemiological studies have consistently shown that breast cancer incidence tends to be higher in high-income countries, largely due to reproductive patterns, lifestyle factors, and screening practices (Bray et al., 2018; Sung et al., 2021). However, mortality rates do not follow the same pattern. High-income countries often demonstrate lower mortality-to-incidence ratios because of early detection programs and access to advanced treatment (Allemani et al., 2018).

For example, the CONCORD-3 study reported substantial international disparities in breast cancer survival, with five-year survival exceeding 85% in several high-income countries but remaining below 60% in some low- and middle-income settings (Allemani et al., 2018). These findings suggest that health system capacity and access to quality care may play a more decisive role than macroeconomic indicators alone.

Furthermore, socioeconomic gradients in cancer outcomes have been documented within countries. Studies have demonstrated that income inequality, educational attainment, and health insurance coverage significantly influence cancer mortality independent of national GDP (Marmot, 2005; Jemal et al., 2017). GDP, as an aggregate measure, does not capture internal disparities or health system efficiency, which may explain its limited explanatory power in this analysis. The absence of a statistically significant relationship in this study may also reflect several methodological considerations. First, the relatively small sample size ($n = 27$) may limit statistical power. Second, GDP is an aggregate macroeconomic indicator and does not capture income distribution, healthcare expenditure, or health system efficiency. Furthermore, breast cancer mortality is influenced by multifactorial determinants, including stage at diagnosis, screening coverage, treatment availability, lifestyle factors and genetic predisposition. Consequently, the weak association observed suggests that breast cancer mortality is better explained by proximal healthcare and epidemiological variables rather than by GDP alone.

In conclusion, the results demonstrate that GDP does not have a statistically significant or practically meaningful relationship with breast cancer mortality in this dataset. These findings underscore the importance of examining healthcare system characteristics and public health strategies rather than relying solely on macroeconomic indicators when investigating determinants of cancer mortality.

4.10 GDP and Cervical cancer mortality

To evaluate the association between gross domestic product (GDP) and cervical cancer mortality, a Spearman's rank-order correlation analysis was performed using 27 observations. Spearman's correlation was selected due to its non-parametric nature and its suitability for assessing monotonic relationships without assuming normality of the variables.

Table 19. Spearman's correlation analysis for testing the relationship between *GDP* and *Cervical cancer mortality*

Parameter	Value
Spearman's rank correlation coefficient (r_s)	-0.2668
r^2	0.07117
P-value	0.1786
Covariance	-16.7885
Sample size (n)	27
Statistic	-1.384

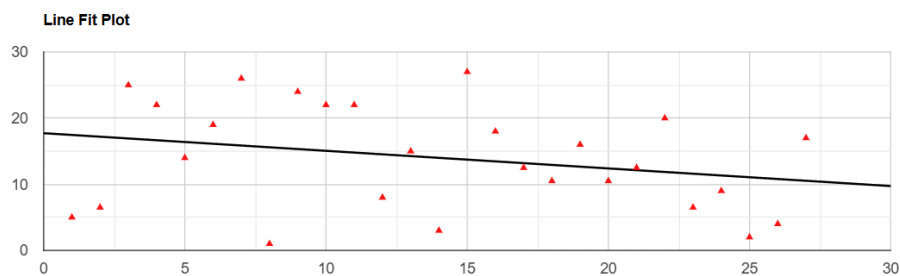


Figure 34. Line Fit Plot for testing the relationship between *GDP* and *Cervical cancer mortality*

Results of the Spearman correlation indicated that there is a non-significant small negative relationship between X and Y, ($r(25) = 0.267$, $p = 0.179$). The analysis yielded a correlation coefficient of $r_s = -0.267$, indicating a small negative association between GDP and cervical cancer mortality. This suggests that countries with higher GDP levels tend to report lower cervical cancer mortality rates; however, the strength of this relationship is modest. The coefficient of determination ($r^2 = 0.071$) indicates that approximately 7.1% of the variation in cervical cancer mortality can be explained by GDP. While larger than that observed for breast cancer mortality, this proportion remains relatively small.

The association was not statistically significant ($p = 0.179$), as the p-value exceeded the conventional alpha level of 0.05. Visual inspection of the line fit plot demonstrates a downward-sloping regression line with moderate dispersion of data points, consistent with a weak negative but non-significant relationship. In summary, although a small inverse association was observed, GDP was not found to be a statistically significant predictor of cervical cancer mortality in this dataset. Cervical cancer exhibits one of the strongest global socioeconomic gradients among all major cancers. Unlike breast cancer, cervical cancer is largely preventable through human papillomavirus (HPV) vaccination, organized screening programs, and timely treatment of precancerous lesions (WHO, 2020). Consequently, disparities in mortality are strongly linked to differences in health system capacity and public health infrastructure.

Global cancer statistics consistently demonstrate that cervical cancer mortality is disproportionately concentrated in low- and middle-income countries (Bray et al., 2018; Sung et al., 2021). Nearly 90% of cervical cancer deaths occur in less developed regions, reflecting limited access to screening and treatment services. Countries with higher income levels generally show substantially lower mortality rates due to widespread implementation of Pap smear screening and, more recently, HPV vaccination programs (Arbyn et al., 2020). The CONCORD-3 study reported significant international disparities in cervical cancer survival, with five-year survival exceeding 65–70% in many high-income countries but remaining considerably lower in resource-constrained settings (Allemani et al., 2018). These findings suggest that economic development may influence mortality indirectly through healthcare infrastructure and access.

However, GDP as a macroeconomic aggregate does not necessarily capture effective health service delivery. Research indicates that specific health system indicators, such as screening coverage, vaccination uptake, and oncology service availability, are more strongly associated with cervical cancer outcomes than national income alone (Karanikolos et al., 2013; Arbyn et al., 2020). Furthermore, social determinants including education, gender inequality, and rural/urban disparities significantly influence cervical cancer risk and mortality (Marmot, 2005). Thus, while GDP may provide a broad contextual measure of development, it does not reflect the distribution of healthcare resources or the effectiveness of prevention strategies.

The findings highlight that while economic development may contribute to improved cervical cancer outcomes, GDP alone is not a sufficient explanatory variable. Policymakers should prioritize targeted interventions, including HPV vaccination programs, organized screening systems and equitable access to treatment services.

4.11 GDP and Colorectal cancer mortality

To evaluate the association between gross domestic product and colorectal cancer mortality, a Spearman's rank-order correlation analysis was performed using 27 observations. Spearman's correlation was selected due to its non-parametric nature and its suitability for assessing monotonic relationships without assuming normality of the variables.

Table 20. Spearman's correlation analysis for testing the relationship between *GDP and Colorectal cancer mortality*

Parameter	Value
Spearman's rank correlation coefficient (r_s)	-0.2296
r^2	0.05271
P-value	0.2493
Covariance	-14.4615
Sample size (n)	27
Statistic	-1.1794

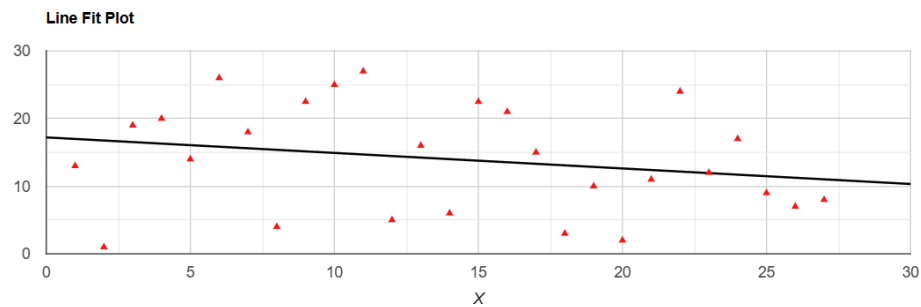


Figure 35. Line Fit Plot for testing the relationship between *GDP and Colorectal cancer mortality*

Results of the Spearman correlation indicated that there is a non-significant small negative relationship between X and Y, ($r(25) = 0.23$, $p = 0.249$). The analysis yielded a Spearman's correlation coefficient of $r_s = -0.2296$, indicating a very weak negative association between GDP and colorectal cancer mortality. The negative direction suggests that higher GDP levels are marginally associated with lower colorectal cancer mortality rates. However, the magnitude of the coefficient indicates that this relationship is negligible in practical terms. The coefficient of determination ($r^2 = 0.0527$) indicates that approximately 5.27% of the variability in colorectal cancer mortality can be explained by GDP. This proportion of explained variance is extremely small and suggests minimal predictive value. The correlation was not statistically significant ($p = 0.249$). Although a small inverse association was observed, GDP was not found to be a statistically significant predictor of colorectal cancer mortality in this dataset. Colorectal cancer remains one of the most significant contributors to cancer-related mortality globally, and understanding the socioeconomic determinants of this burden has become increasingly important in global health research. While GDP has long been used as a proxy for economic development and a broad indicator of healthcare capacity and societal well-being, its specific relationship with colorectal cancer mortality is complex and mediated by multiple contextual factors. Allemani et al. (2018), through the CONCORD-3 programme, showed improved colorectal cancer survival in high-income countries. Studies from Latin America demonstrate increasing mortality trends in middle-income settings lacking comprehensive screening coverage (Arnold et al., 2017). A meta-analysis synthesizing over 37 studies (with more than 2 million patients) documented that lower income, lower educational attainment, and reduced insurance coverage are strongly associated with poorer colorectal cancer survival (Chua et al., 2025). Although this review focuses on individual-level SES rather than national GDP, it reinforces the fundamental premise that economic resources, whether at the individual or societal level, are critical determinants of mortality outcomes. While GDP is positively associated with general population health, its relationship with colorectal cancer mortality is indirect and mediated by health system capacity, screening implementation, resource allocation, and socioeconomic equity. Higher GDP generally facilitates advanced medical technologies and pharmaceuticals. However, evidence suggests that health expenditure per capita and equitable access, often alongside GDP, are more predictive of mortality rates (Allemani et al., 2018). Moreover, inefficiencies in health financing systems can blunt the impact of GDP on actual health outcomes. Economic development appears necessary but not sufficient for mortality reduction.

4.12 Healthcare expenditure and Cardiovascular diseases mortality

Table 21. Spearman's correlation analysis for testing the relationship between *Healthcare expenditure in % of GDP* and *Cardiovascular diseases mortality*

Parameter	Value
Spearman's rank correlation coefficient (r_s)	-0.5079
r^2	0.2579
P-value	0.006842
Covariance	-31.9615
Sample size (n)	27
Statistic	-2.9478

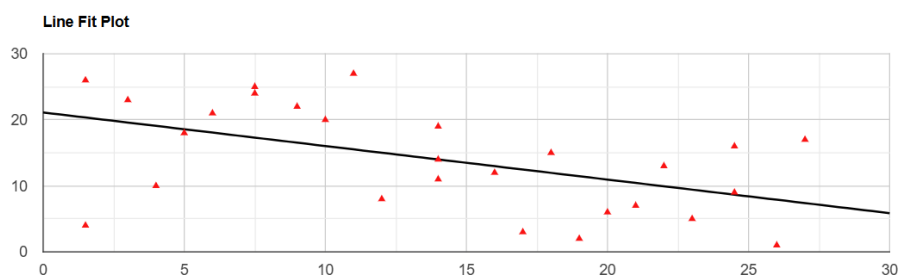


Figure 36. Line Fit Plot for testing the relationship between *Healthcare expenditure in % of GDP* and *Cardiovascular diseases mortality*

Results of the Spearman correlation indicated that there is a **significant large negative relationship** between X and Y, ($r(25) = 0.508$, $p = 0.007$). The results of the Spearman's rank correlation analysis indicate a statistically significant inverse relationship between healthcare expenditure as a percentage of GDP and cardiovascular diseases mortality. The correlation coefficient ($\rho = -0.5079$) suggests a significant large negative association, implying that countries allocating a higher proportion of national income to healthcare tend to experience lower rates of cardiovascular mortality.

The coefficient of determination ($r^2 = 0.2579$) indicates that approximately 25.79% of the variation in CVD mortality across the sampled countries ($n = 27$) can be explained by differences in healthcare expenditure. The negative covariance (-31.9615) further supports the direction of this association. These findings are consistent with existing literature suggesting that increased healthcare investment enhances access to preventive services, early diagnosis, and effective management of cardiovascular conditions, thereby reducing mortality (World Health Organization, 2023; Roth et al., 2020). Moreover, prior cross-national analyses have demonstrated that higher health spending is associated with improved population health outcomes, particularly in relation to non-communicable diseases (Dieleman et al., 2016; Xu et al., 2018). Nevertheless, while healthcare expenditure explains a meaningful proportion of mortality variation, a substantial share remains attributable to other determinants, including socioeconomic conditions, behavioural risk factors, demographic structure, and health system efficiency. Reports from the OECD (2021) demonstrate that OECD countries with sustained growth in public healthcare spending have experienced marked reductions in deaths from ischemic heart disease and stroke over the past three decades. These reductions are attributed to enhanced diagnostic technologies, improved pharmaceutical interventions (e.g., statins and antihypertensives), and better emergency response systems. The moderate strength of the correlation observed in this study is consistent with these cross-national findings. Most large-scale econometric studies report statistically significant but moderate associations, indicating that while healthcare expenditure is an important determinant, it is not the sole driver of mortality outcomes.

The findings suggest that sustained investment in healthcare systems may contribute meaningfully to reducing cardiovascular mortality. Increased healthcare expenditure can strengthen primary prevention programmes, improve early detection of hypertension and hyperlipidaemia, expand access to essential medicines, and enhance acute cardiac care infrastructure. Effective strategies must integrate healthcare financing with public health interventions targeting smoking cessation, dietary improvements, physical activity promotion, and socioeconomic inequalities. Therefore, while increasing healthcare expenditure is a necessary component of cardiovascular disease control, it is insufficient in isolation. Policymakers should prioritise both adequate funding levels and efficient allocation of resources to maximize health returns.

In conclusion, the findings of this study are highly consistent with established global and cross-national research. The moderate, statistically significant negative correlation between healthcare expenditure and cardiovascular mortality supports the prevailing academic consensus that greater health system investment contributes to reduced cardiovascular deaths. However, healthcare expenditure explains only part of the variation in mortality, confirming that cardiovascular health is shaped by a complex interplay of medical, behavioural, socioeconomic, and demographic factors. These findings support the need for integrated policy approaches that combine adequate healthcare financing with comprehensive public health and social interventions.

4.13 Healthcare expenditure and Breast cancer mortality

Table 22. Pearson's correlation analysis for testing the relationship between *Healthcare expenditure in % of GDP* and *Breast cancer mortality*

Parameter	Value
Pearson correlation coefficient (r)	-0.3659
r^2	0.1339
P-value	0.06053
Covariance	-1.5506
Sample size (n)	27
Statistic	-1.9658

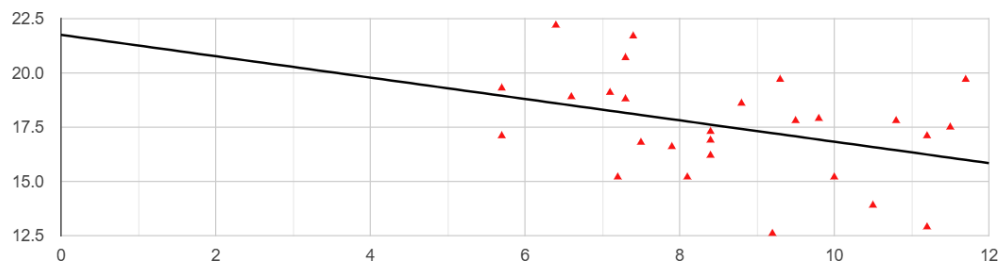


Figure 37. Line Fit Plot for testing the relationship between *Healthcare expenditure in % of GDP* and *Breast cancer mortality*

Results of the Pearson correlation indicated that there is a non-significant medium negative relationship between X and Y, ($r(25) = 0.366$, $p = 0.061$). The Pearson correlation analysis revealed a moderate negative relationship between healthcare expenditure (as a percentage of GDP) and breast cancer mortality ($r = -0.3659$). This indicates that countries allocating a higher proportion of GDP to healthcare tend to experience lower breast cancer mortality rates. However, the relationship was not statistically significant at the 5% level ($p = 0.06053$). The coefficient of determination ($r^2 = 0.1339$) suggests that approximately 13.39% of the variation in breast cancer mortality across the 27 countries is explained by differences in healthcare expenditure. The negative covariance (-1.5506) supports the inverse direction of the association, and the downward slope observed in the line fit plot visually confirms this pattern.

The direction of the relationship is consistent with global evidence reported by the World Health Organization (2023), which emphasizes that improved health system capacity, particularly in screening, early detection, and oncology treatment, contributes to reductions in breast cancer mortality. Increased healthcare expenditure enhances access to mammography programmes, pathology services, chemotherapy, radiotherapy, and targeted therapies, all of which are critical for improving survival outcomes.

However, unlike the stronger and statistically significant relationship observed for cardiovascular mortality in this study, the association between healthcare expenditure and breast cancer mortality is weaker and statistically non-significant. This partial divergence from the broader literature may reflect the complex epidemiology of breast cancer.

While improved healthcare systems reduce mortality through early detection and advanced treatment, incidence rates are often higher in high-income countries due to lifestyle and reproductive factors, such as delayed childbirth, lower parity, obesity, and hormonal influences. As a result, higher-spending countries may exhibit high incidence but relatively better survival, thereby moderating the overall mortality relationship. Global cancer burden analyses conducted by Sung et al. (2021) reveal that high-income countries often exhibit lower case-fatality rates for breast cancer compared to low- and middle-income countries. This survival advantage is frequently attributed to stronger health systems, advanced diagnostic technologies, and greater public investment in oncology services.

Furthermore, research by Allemani et al. (2018) shows that five-year breast cancer survival rates exceed 80% in many high-income countries but remain substantially lower in resource-constrained settings. It demonstrates that improvements in breast cancer survival are closely linked to early-stage diagnosis and timely treatment rather than healthcare expenditure alone. This suggests that allocation efficiency, screening coverage, and equity in access may be more influential than aggregate spending levels. The literature increasingly emphasizes that the impact of healthcare expenditure on breast cancer mortality operates primarily through screening and early detection mechanisms. The International Agency for Research on Cancer highlights that organized mammography screening programmes significantly reduce mortality when implemented effectively and equitably. Countries that invest in nationwide screening programmes tend to detect cancers at earlier stages, thereby improving survival outcomes.

Although the relationship is not statistically significant at the conventional 5% level, the negative direction of the correlation suggests that increased healthcare expenditure may still contribute to reductions in breast cancer mortality. In summary, the analysis reveals a moderate but statistically non-significant negative relationship between healthcare expenditure and breast cancer mortality. While the direction of association aligns with global evidence suggesting that stronger health systems improve cancer survival, the weaker magnitude and lack of statistical significance highlight the complexity of breast cancer epidemiology. Compared to cardiovascular disease mortality, healthcare expenditure appears to exert a less pronounced and less immediate influence on breast cancer outcomes. These findings underscore the importance of considering disease-specific pathways, screening coverage, and healthcare efficiency when evaluating the impact of health financing on mortality outcomes.

4.14 Healthcare expenditure and Cervical cancer mortality

Cervical cancer remains a leading cause of cancer mortality among women globally, with significant disparities observed between countries (Bray et al., 2018).

Table 23. Spearman's correlation analysis for testing the relationship between *Healthcare expenditure in % of GDP* and *Cervical cancer mortality*

Parameter	Value
Spearman's rank correlation coefficient (r_s)	-0.4711
r^2	0.2219
P-value	0.01313
Covariance	-29.6154
Sample size (n)	27
Statistic	-2.6703

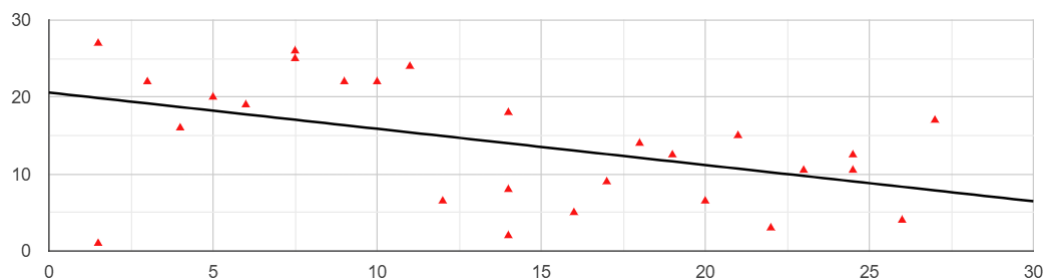


Figure 38. Line Fit Plot for testing the relationship between *Healthcare expenditure in % of GDP* and *Cervical cancer mortality*

Results of the Spearman correlation indicated that there is a **significant medium negative relationship** between X and Y, ($r(25) = 0.471$, $p = 0.013$).

Spearman's rank-order correlation was conducted to examine the relationship between healthcare expenditure (as a percentage of GDP) and cervical cancer mortality. The analysis revealed a moderate negative correlation between the two variables ($r_s = -0.471$, $n = 27$, $p = 0.013$). The negative coefficient indicates that countries with higher healthcare expenditure as a proportion of GDP tend to have lower cervical cancer mortality rates.

The coefficient of determination ($r^2 = 0.222$) indicates that approximately 22.2% of the variability in cervical cancer mortality can be explained by differences in healthcare expenditure. While this represents a meaningful proportion, it also suggests that additional factors, such as screening coverage, HPV vaccination uptake, early detection programs, socioeconomic conditions, and healthcare system efficiency, may substantially influence mortality outcomes. Overall, the findings suggest that increased investment in healthcare is associated with reduced cervical cancer mortality. A substantial body of research highlights the role of healthcare expenditure as a critical factor influencing cervical cancer outcomes. Healthcare spending, often quantified as a percentage of GDP, reflects the resources allocated to prevention, early detection, and treatment services (WHO, 2020). Several studies have demonstrated that higher healthcare expenditure is associated with increased cervical cancer screening coverage and HPV vaccination rates, which are essential for reducing incidence and mortality (Jemal et al., 2011). Torre et al. (2015) further emphasized that better-funded healthcare systems enable improved access to curative treatments such as surgery and radiotherapy, contributing to enhanced survival rates. However, healthcare expenditure is not the sole determinant of cervical cancer mortality. Research indicates that social determinants, health system efficiency, and equitable access to services also play crucial roles (Arbyn et al., 2020; Atun et al., 2015). This complexity explains why variations in mortality persist even among countries with comparable spending levels.

The present study's findings align well with the existing literature. A moderate negative correlation (Spearman's $r_s = -0.471$, $p = 0.013$) was observed between healthcare expenditure (% of GDP) and cervical cancer mortality, indicating that higher investment in healthcare is significantly associated with reduced mortality rates. This supports the notion that increased healthcare resources facilitate prevention and treatment efforts, thereby improving cervical cancer outcomes. The coefficient of determination ($r^2 = 0.222$) found in this analysis suggests that healthcare expenditure accounts for approximately 22% of the variability in cervical cancer mortality. This partial explanatory power is consistent with previous studies emphasizing that while expenditure is important, other factors such as socioeconomic conditions, health policy, and system efficiency also critically influence mortality rates (Arbyn et al., 2020; Atun et al., 2015). Overall, the results corroborate the consensus in the literature that healthcare investment is a key but not exclusive factor in reducing cervical cancer mortality, highlighting the need for comprehensive strategies addressing both financial and systemic determinants.

4.15 Healthcare expenditure and Colorectal cancer mortality

Table 24. Spearman's correlation analysis for testing the relationship between *Healthcare expenditure in % of GDP* and *Colorectal cancer mortality*

Parameter	Value
Spearman's rank correlation coefficient (r_s)	-0.5344
r^2	0.2856
P-value	0.004087
Covariance	-33.625
Sample size (n)	27
Statistic	-3.1611

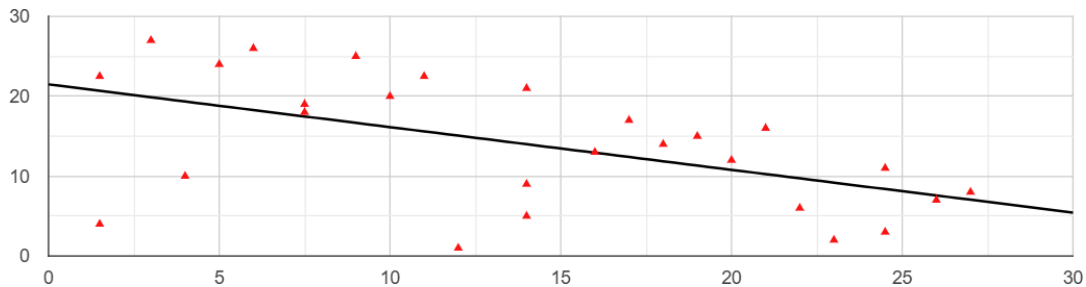


Figure 39. Line Fit Plot for testing the relationship between *Healthcare expenditure in % of GDP* and *Colorectal cancer mortality*

Results of the Spearman correlation indicated that there is a **significant large negative relationship** between X and Y, ($r(25) = 0.534$, $p = 0.004$).

Spearman's rank-order correlation was conducted to examine the association between healthcare expenditure (as a percentage of GDP) and colorectal cancer mortality. The analysis revealed a statistically significant moderate negative correlation between the two variables ($r_s = -0.5344$, $p = 0.0041$). This indicates that higher levels of healthcare expenditure were associated with lower colorectal cancer mortality rates.

The coefficient of determination ($r^2 = 0.2856$) suggests that approximately 28.6% of the variability in colorectal cancer mortality can be explained by differences in healthcare spending in a monotonic context. The negative test statistic ($Z = -3.1611$) further supports the statistical significance of this inverse relationship. Overall, the findings provide evidence of a meaningful and statistically significant inverse association between national healthcare investment and colorectal cancer mortality within the study sample.

Colorectal cancer remains one of the most commonly diagnosed malignancies and a leading cause of cancer-related mortality worldwide. High-income countries have experienced declining mortality rates over recent decades despite stable or increasing incidence, largely attributable to organized screening programmes and advancements in treatment (Arnold et al., 2017). The inverse association observed in the present study aligns closely with these international trends, supporting the proposition that greater healthcare expenditure facilitates mortality reduction. Brenner et al. (2014) demonstrated through systematic review and meta-analysis that screening colonoscopy substantially reduces colorectal cancer mortality. Consequently, the moderate negative correlation identified in this study is biologically and systemically plausible, as increased investment enhances early detection and the removal of precancerous lesions. Beyond screening, healthcare expenditure influences colorectal cancer outcomes through diagnostic capacity, treatment accessibility, and technological advancement. High-expenditure systems are more likely to provide access to multidisciplinary oncology care, advanced imaging technologies, minimally invasive surgical techniques, and novel chemotherapeutic and targeted therapies.

However, while the statistically significant association found in this study supports the importance of healthcare spending, the moderate strength of correlation warrants careful interpretation. An r^2 value of 0.2856 indicates that more than 70% of mortality variation remains unexplained by expenditure alone. This is consistent with research suggesting diminishing returns beyond certain spending thresholds. Bradley et al. (2008) argue that efficiency, equity, and organization of services may influence outcomes as strongly as total financial input. For example, some countries achieve comparable cancer survival outcomes with lower relative expenditure by optimizing primary care integration, referral pathways, and universal coverage mechanisms.

Therefore, while the present findings confirm the importance of investment, they also imply that how resources are allocated may be as critical as the volume of spending itself. Socioeconomic determinants further complicate the relationship between healthcare expenditure and mortality. Colorectal cancer risk is strongly associated with modifiable behavioural factors, including diet high in processed meat, obesity, alcohol consumption, smoking, and physical inactivity (Arnold et al., 2017). These factors vary considerably across countries and are influenced by broader social and economic contexts. Additionally, disparities in education and health literacy affect screening uptake and adherence to treatment. Consequently, the unexplained variance in the present study may reflect heterogeneity in lifestyle risk factors, cultural norms, and public health policies rather than deficiencies in healthcare spending per se.

In conclusion, the present study provides empirical support for a statistically significant moderate inverse relationship between healthcare expenditure and colorectal cancer mortality. The findings are consistent with international evidence demonstrating that higher levels of national health investment contribute to improved cancer outcomes. Nevertheless, the moderate effect size indicates that expenditure alone does not fully account for mortality differences. Broader structural, behavioural, and socioeconomic determinants remain influential. Future research incorporating multivariable modelling and longitudinal data would further clarify the pathways through which healthcare investment translates into mortality reduction.

4.16 Multiple regression analysis of the effect of GDP and Participation in breast cancer screening test on Breast cancer mortality

Table 25. Multiple regression analysis (x1 *GDP*, x2 *Participation in breast cancer screening test*, y *Breast cancer mortality*)

Correlation matrix (pearson)			
	Y	X ₁	X ₂
Y	1	-0.0179209	-0.300905
X ₁	-0.0179209	1	-0.00565177
X ₂	-0.300905	-0.00565177	1

ANOVA table					
Source	DF	Sum of Square	Mean Square	F Statistic	P-value
Regression (between $\hat{y}_i$ and $\bar{y}$)	1	12.811764	12.811764	2.190274	0.153063
Residual (between y_i and $\hat{y}_i$)	22	128.68657	5.84939		
Total (between y_i and $\bar{y}$)	23	141.498333	6.152101		

Results of the multiple linear regression indicated that there was a weak collective non-significant effect between the X1, X2, and Y, ($F(1, 22) = 2.19$, $p = 0.153$, $R^2 = 0.09$, $R^2_{adj} = 0.05$). A multiple linear regression model was estimated to assess the combined effect of GDP (X₁) and participation in breast cancer screening (X₂) on breast cancer mortality (Y). Pearson's correlation coefficients indicated a very weak negative association between GDP and mortality ($r = -0.018$) and a weak negative association between screening participation and mortality ($r = -0.301$). The correlation between GDP and screening participation was negligible ($r = -0.006$), suggesting no evidence of multicollinearity. The ANOVA results indicated that the overall regression model was not statistically significant, $F(1, 22) = 2.19$, $p = 0.150$. The coefficient of determination ($R^2 \approx 0.091$) suggests that approximately 9.1% of the variance in breast cancer mortality is explained by GDP and screening participation combined.

The findings can be interpreted within the framework of the social determinants of health, which posits that macroeconomic development influences health outcomes indirectly through structural and institutional pathways (World Health Organization, 2008). GDP reflects aggregate economic capacity but does not directly measure how resources are distributed, nor how effectively they are translated into healthcare access, preventive services, or treatment quality. From a health production function perspective (Grossman, 1972), health outcomes such as cancer mortality are produced through a combination of medical care, preventive behavior, and socioeconomic inputs. GDP may increase the potential for investment in health systems, but without efficient allocation, institutional quality, and equitable access, economic growth alone may not reduce mortality.

Furthermore, screening theory suggests that organized mammography programs reduce mortality primarily through early detection and stage migration. Evaluations by the International Agency for Research on Cancer indicate that well-organized screening programs can significantly reduce breast cancer mortality, but effectiveness depends heavily on quality assurance, follow-up systems, and treatment availability (IARC, 2016). The negligible relationship between GDP and breast cancer mortality observed in this study aligns with international evidence showing that economic development alone is not a sufficient predictor of cancer outcomes. According to data from GLOBOCAN, high-income countries often exhibit high incidence rates but variable mortality rates, largely depending on healthcare system performance (Sung et al., 2021).

Comparative analyses among OECD countries demonstrate that survival differences are more strongly associated with healthcare expenditure efficiency, early diagnosis, and access to modern therapies than with GDP per capita alone (OECD, 2019). Thus, GDP may function as a distal determinant whose effects are mediated by structural healthcare variables not included in the present model.

The weak inverse association between screening participation and mortality is consistent with established literature demonstrating that mammography screening can reduce breast cancer mortality. A meta-analysis by Nelson et al. (2016) found that screening mammography is associated with a reduction in breast cancer mortality among women aged 50-69 years. Similarly, long-term European evaluations reported mortality reductions following implementation of organized screening programs (Tabár et al., 2011).

However, the absence of statistical significance in this model may reflect several factors:

1. Time-lag effects: Mortality reductions from screening typically become evident years after implementation (Tabár et al., 2011).
2. Program heterogeneity: Participation rates do not capture screening quality, diagnostic accuracy, or adherence to follow-up protocols (IARC, 2016).
3. Therapeutic advancements: Improvements in systemic therapies and targeted treatments have substantially contributed to mortality reductions independently of screening (Berry et al., 2005).
4. Ecological limitations: National-level screening data may conceal within-country disparities.

Evidence suggests that declines in breast cancer mortality since the 1990s are attributable to both screening expansion and advances in treatment (Berry et al., 2005), reinforcing the importance of including healthcare system variables in future models. The findings indicate that GDP and participation in breast cancer screening explain only a small proportion of the variance in breast cancer mortality. While screening participation demonstrates a protective tendency consistent with international evidence, neither predictor achieves statistical significance within the present model. The results support theoretical perspectives emphasizing that economic development must be translated into effective health system organization and equitable access to care to influence mortality outcomes. A multidimensional framework incorporating structural, clinical, and socioeconomic variables is therefore essential for more robust modelling of breast cancer mortality determinants.

4.17 Multiple regression analysis of the effect of GDP and Participation in cervical cancer screening test on Cervical cancer mortality

Table 26. Multiple regression analysis (x1 *GDP*, x2 *Participation in cervical cancer screening test*, y *Cervical cancer mortality*)

Correlation matrix (pearson)			
	Y	X ₁	X ₂
Y	1	-0.323192	-0.330453
X ₁	-0.323192	1	-0.107394
X ₂	-0.330453	-0.107394	1

ANOVA table					
Source	DF	Sum of Square	Mean Square	F Statistic	P-value
Regression (between $\hat{y}_i$ and $\bar{y}$)	1	27.171602	27.171602	2.206543	0.15473
Residual (between y_i and $\hat{y}_i$)	18	221.653898	12.314105		
Total (between y_i and $\bar{y}$)	19	248.8255	13.096079		

Results of the multiple linear regression indicated that there was a weak collective non-significant effect between the X1, X2, and Y, ($F(1, 18) = 2.21$, $p = 0.155$, $R^2 = 0.11$, $R^2_{adj} = 0.06$). A multiple linear regression analysis was performed to examine the combined effect of GDP (X₁) and participation in cervical cancer screening (X₂) on cervical cancer mortality (Y). Pearson's correlation analysis revealed moderate negative associations between GDP and mortality ($r = -0.323$) and between screening participation and mortality ($r = -0.330$), indicating that higher GDP levels and greater screening participation are both associated with lower cervical cancer mortality. The correlation between GDP and screening participation was weak ($r = -0.107$), suggesting no evidence of multicollinearity. The overall regression model was not statistically significant, $F(1, 18) = 2.21$, $p = 0.155$, with $R^2 = 0.11$ and adjusted $R^2 = 0.06$.

The findings can be interpreted through the lens of the social determinants of health framework, which emphasizes that structural economic conditions influence health outcomes indirectly via healthcare access, preventive services, and institutional capacity (WHO, 2008). GDP represents macroeconomic development, but its effect on cervical cancer mortality is mediated by the strength of primary care systems, screening organization, and access to treatment. The moderate inverse correlation between screening participation and mortality is consistent with substantial international evidence demonstrating that cytology-based and HPV-based screening programs significantly reduce cervical cancer mortality. Cervical cancer is widely regarded as a preventable disease through effective screening and early treatment of precancerous lesions. The World Health Organization has emphasized that cervical cancer is largely preventable through organized screening and HPV vaccination strategies (WHO, 2020).

Evaluations summarized by the International Agency for Research on Cancer indicate that organized cervical screening programs can reduce incidence and mortality by up to 80% when high coverage and quality follow-up are achieved (IARC, 2005). Long-term observational data from Nordic countries show marked declines in cervical cancer mortality following implementation of population-based screening programs. The moderate negative association between GDP and cervical cancer mortality is theoretically consistent with global epidemiological patterns. Data from GLOBOCAN demonstrate that cervical cancer mortality is disproportionately concentrated in low- and middle-income countries (Sung et al., 2021). Higher-income countries typically exhibit lower mortality due to stronger screening infrastructure, better treatment access, and more comprehensive public health systems. Comparative evidence from OECD countries suggests that mortality reductions are closely linked to organized screening coverage and universal access to care rather than GDP alone (OECD, 2019). Therefore, GDP likely operates as a distal determinant whose influence is mediated by health system organization and equity. The present R^2 value of 11% suggests that GDP and screening participation together explain only a small fraction of mortality variance. This implies that additional structural variables, such as healthcare expenditure per capita, rural–urban inequalities, HPV vaccination coverage, and health system governance, should be incorporated into future models.

In conclusion, the multiple regression analysis indicates that GDP and participation in cervical cancer screening explain approximately 11% of the variation in cervical cancer mortality. Although both predictors show theoretically consistent inverse associations with mortality, the combined model is not statistically significant at the 5% level. These findings reinforce the understanding that cervical cancer mortality is influenced by a complex interplay of economic capacity, preventive service organization, and healthcare system effectiveness. While screening participation and economic development are important structural factors, their impact on mortality depends on broader systemic and institutional conditions.

4.18 Multiple regression analysis of the effect of GDP and Participation in colorectal cancer screening test on Colorectal cancer mortality

Table 27. Multiple regression analysis (x1 *GDP*, x2 *Participation in colorectal cancer screening test*, y *Colorectal cancer mortality*)

Correlation matrix (pearson)			
	Y	X ₁	X ₂
Y	1	-0.375818	-0.509592
X ₁	-0.375818	1	-0.0878707
X ₂	-0.509592	-0.0878707	1

ANOVA table					
Source	DF	Sum of Square	Mean Square	F Statistic	P-value
Regression (between $\hat{y}_i$ and $\bar{y}$)	2	539.58673	269.793365	6.233904	0.00995698
Residual (between y_i and $\hat{y}_i$)	16	692.454322	43.278395		
Total (between y_i and $\bar{y}$)	18	1232.041053	68.446725		

Results of the multiple linear regression indicated that there was a **strong collective significant effect** between the X1, X2, and Y, ($F(2, 16) = 6.23$, $p = 0.010$, $R^2 = 0.44$, $R^2_{adj} = 0.37$). The individual predictors were examined further and indicated that X1 ($t = -2.253$, $p = 0.039$) and X2 ($t = -2.906$, $p = 0.010$) were significant predictors in the model.

A multiple linear regression analysis was conducted to evaluate the combined effect of GDP (X_1) and participation in colorectal cancer screening (X_2) on colorectal cancer mortality (Y). Pearson's correlation coefficients indicated a moderate negative correlation between GDP and mortality ($r = -0.376$) and a stronger negative correlation between screening participation and mortality ($r = -0.510$), suggesting that higher GDP levels and greater screening participation are associated with lower colorectal cancer mortality. The correlation between GDP and screening participation was weak ($r = -0.088$), indicating no multicollinearity concerns. The overall regression model was statistically significant, $F(2, 16) = 6.23$, $p = 0.010$, with $R^2 = 0.44$ and adjusted $R^2 = 0.37$. This indicates that approximately 44% of the variance in colorectal cancer mortality is explained by GDP and screening participation combined. Both GDP ($t = -2.253$, $p = 0.039$) and screening participation ($t = -2.906$, $p = 0.010$) were significant independent predictors, demonstrating a strong and statistically significant collective effect on colorectal cancer mortality.

The significant findings observed in the colorectal cancer model can be interpreted within three complementary theoretical perspectives: (1) the social determinants of health framework, (2) the health production function model, and (3) preventive screening theory. The social determinants of health framework, articulated by the World Health Organization (2008), posits that macroeconomic conditions influence health outcomes through structural pathways, including healthcare access, education, living conditions, and institutional capacity. GDP serves as an indicator of national economic resources and potential investment in healthcare infrastructure. Unlike in the breast and cervical cancer models, GDP demonstrated a statistically significant independent association with colorectal cancer mortality, suggesting that economic capacity may play a more direct role in shaping outcomes for this disease.

From a health production function perspective (Grossman, 1972), health outcomes are produced through investments in preventive care, medical treatment, and human capital. Colorectal cancer provides a clear example of this framework in action: mortality reduction depends on screening uptake, early detection, availability of endoscopic services, surgical capacity, and access to adjuvant therapies. The significant R^2 value (44%) indicates that macroeconomic resources and preventive participation together constitute meaningful inputs in the “production” of improved colorectal cancer outcomes.

Preventive screening theory further supports these findings. Colorectal cancer screening via fecal occult blood testing (FOBT), fecal immunochemical testing (FIT), sigmoidoscopy, or colonoscopy, not only enables early detection but also allows removal of precancerous adenomas, thereby preventing cancer development altogether. This dual preventive and early detection function distinguishes colorectal cancer from some other malignancies and strengthens the theoretical expectation of a strong screening–mortality relationship. The results align closely with international epidemiological evidence. Data from GLOBOCAN indicate substantial variation in colorectal cancer mortality across countries, with lower mortality generally observed in high-income nations with organized screening programs (Sung et al., 2021). Randomized controlled trials and long-term follow-up studies have demonstrated that fecal occult blood test screening reduces colorectal cancer mortality by approximately 15–33% (Mandel et al., 1993; Hewitson et al., 2008). Furthermore, colonoscopy-based screening has been associated with even greater reductions in incidence and mortality due to its ability to detect and remove precancerous lesions (Zauber et al., 2012).

Comparative analyses within OECD countries show that nations implementing organized population-based colorectal screening programs experience more pronounced mortality declines compared to those relying on opportunistic screening (OECD, 2019). These findings support the strong inverse association observed between screening participation and mortality in the present analysis. Importantly, Berry et al. (2005) demonstrated that for several cancers, mortality reductions are attributable to both screening and improvements in treatment. In colorectal cancer, advancements in surgical techniques, perioperative care, chemotherapy, and targeted therapies have significantly improved survival outcomes. Therefore, the observed significant effect of GDP may reflect enhanced access to high-quality oncological treatment and diagnostic services in wealthier countries.

The statistically significant negative association between GDP and colorectal cancer mortality suggests that economic development plays a meaningful structural role. Higher GDP levels are typically associated with:

- Greater healthcare expenditure per capita
- Wider availability of colonoscopy services
- Stronger primary care systems
- Higher public awareness and health literacy
- Improved access to multimodal cancer treatment

Unlike cervical cancer which is strongly preventable through organized cytology programs or breast cancer which is influenced heavily by tumor biology and treatment advancements, colorectal cancer mortality appears particularly sensitive to health system capacity and technological availability. Endoscopic infrastructure and surgical oncology services are resource-intensive and may therefore be more directly influenced by national economic strength. Thus, GDP may function not merely as a distal determinant but as a proxy for health system sophistication and technological diffusion in colorectal cancer care. When compared with the findings for breast and cervical cancer presented in Sections 4.16 and 4.17, the colorectal cancer model demonstrates substantially higher explanatory power ($R^2 = 0.44$ versus 9% and 11%, respectively). This contrast suggests disease-specific differences in how macroeconomic and screening variables translate into mortality outcomes. Colorectal cancer screening has a unique preventive mechanism, removal of precancerous polyps, which may produce more direct and measurable population-level mortality effects. By contrast, breast cancer screening primarily enables earlier detection rather than true prevention, and cervical cancer outcomes may depend more heavily on HPV prevalence and vaccination coverage. These distinctions reinforce the importance of disease-specific modelling in health economics research and caution against assuming uniform effects of GDP or screening across cancer types.

Despite the strong findings, several methodological considerations should be acknowledged:

- The sample size ($n = 19$) remains relatively small, which may affect generalizability.
- Cross-sectional analysis limits causal inference.
- Potential omitted variables (e.g., healthcare expenditure, stage distribution, lifestyle risk factors such as obesity and diet) may influence outcomes.
- Ecological analysis cannot capture individual-level behavioral determinants.

Future research should incorporate longitudinal panel data to examine temporal relationships between screening expansion and mortality decline, as well as multilevel modelling approaches to account for within-country heterogeneity. In conclusion, the multiple regression analysis demonstrates a strong and statistically significant combined effect of GDP and participation in colorectal cancer screening on colorectal cancer mortality. Together, these variables explain 44% of the variation in mortality across the sample, with both predictors independently contributing to the model.

These findings are consistent with theoretical frameworks emphasizing the role of macroeconomic capacity and preventive investment in producing improved health outcomes. They also align with robust empirical evidence demonstrating that organized colorectal cancer screening and effective treatment infrastructure substantially reduce mortality. The results underscore the importance of integrating economic development with organized preventive health strategies to achieve sustained reductions in colorectal cancer mortality. From a policy perspective, investment in screening infrastructure and equitable access to diagnostic and treatment services appears critical for improving population-level outcomes.

4.18.1 Comparative statistical findings

This chapter synthesizes the findings from Sections 4.16-4.18, which examined the effects of GDP and participation in cancer screening on mortality outcomes for breast, cervical and colorectal cancers. While each model assessed the same structural predictors, economic development (GDP) and screening participation, the strength, direction, and statistical significance of associations varied substantially across cancer types. The comparative analysis reveals important disease-specific differences in how macroeconomic capacity and preventive service uptake translate into mortality reduction. These differences offer both theoretical insight and practical policy implications. Across the three cancer types, the explanatory power of the regression models varied markedly:

Table 28. Comparison of the cancer types and results of a multiple linear regression

Cancer type	Model significance	R²	Screening significant	GDP significant
Breast cancer	Not significant	0.09	no	no
Cervical cancer	Not significant	0.11	no	no
Colorectal cancer	Significant (p = 0.010)	0.44	yes	yes

The colorectal cancer model demonstrated substantially greater explanatory power ($R^2 = 44\%$) compared with breast (9%) and cervical (11%) cancer models. Furthermore, both GDP and screening participation were statistically significant independent predictors only in the colorectal cancer model. These findings indicate that the structural determinants of cancer mortality operate differently across disease types, despite similar modeling frameworks. The social determinants of health framework (WHO, 2008) posits that economic development shapes health outcomes through institutional and structural pathways. However, the present findings suggest that the degree to which GDP translates into mortality reduction is disease-specific.

For breast and cervical cancer, GDP did not demonstrate a statistically significant independent association with mortality. This suggests that economic capacity alone may not sufficiently capture the structural complexities underlying these diseases. The divergent findings can also be explained through preventive screening theory.

- Breast cancer screening primarily enables earlier detection rather than true prevention. Mortality reductions depend not only on mammography uptake but also on advances in systemic therapy (Berry et al., 2005).
- Cervical cancer screening detects precancerous lesions, but effectiveness depends heavily on program organization, follow-up systems, and treatment compliance (IARC, 2005).
- Colorectal cancer screening, particularly colonoscopy, allows for removal of adenomatous polyps before malignant transformation, offering both preventive and early detection benefits (Zauber et al., 2012).

This preventive capacity likely explains the stronger statistical relationship between screening participation and mortality observed in the colorectal cancer model. The findings are consistent with global data from GLOBOCAN showing substantial mortality reductions in countries with organized colorectal screening programs (Sung et al., 2021). The comparative findings yield several important policy implications for governments and public health systems.

The strong findings for colorectal cancer underscore the importance of organized screening programs with high coverage and systematic follow-up. Screening effectiveness depends not only on participation rates but also on diagnostic accuracy, compliance, and timely treatment. Screening alone is insufficient to reduce mortality without accessible, high-quality treatment. The colorectal findings suggest that economic investment in endoscopy services, surgical oncology, radiotherapy infrastructure and chemotherapy and targeted therapy access plays a critical role in translating early detection into survival gains. Integrated cancer control strategies should therefore align preventive and therapeutic capacity. From a research perspective, future studies should incorporate longitudinal data, multilevel modelling, and additional structural health system indicators to deepen understanding of the pathways linking economic development to cancer mortality outcomes.

4.19 Multiple regression analysis of the effect of Healthcare expenditure and Participation in breast cancer screening test on Breast cancer mortality

Table 29. Multiple regression analysis (x1 *Healthcare expenditure in % of GDP*, x2 *Participation in breast cancer screening test*, y *Breast cancer mortality*)

Correlation matrix (pearson)			
	Y	X ₁	X ₂
Y	1	-0.393483	-0.300905
X ₁	-0.393483	1	0.238353
X ₂	-0.300905	0.238353	1

ANOVA table					
Source	DF	Sum of Square	Mean Square	F Statistic	P-value
Regression (between $\hat{y}_i$ and $\bar{y}$)	1	21.907972	21.907972	4.030219	0.0571304
Residual (between y_i and $\hat{y}_i$)	22	119.590361	5.435926		
Total (between y_i and $\bar{y}$)	23	141.498333	6.152101		

Results of the multiple linear regression indicated that there was a weak collective non-significant effect between the X1, X2, and Y, ($F(1, 22) = 4.03$, $p = 0.057$, $R^2 = 0.15$, $R^2_{adj} = 0.12$). A multiple linear regression analysis was conducted to assess the effect of healthcare expenditure (% of GDP) and participation in breast cancer screening on breast cancer mortality. Pearson correlation analysis indicated that breast cancer mortality was negatively associated with both healthcare expenditure ($r = -0.393$) and participation in breast cancer screening ($r = -0.301$). This suggests that higher healthcare spending and greater screening participation are associated with lower mortality rates. The correlation between healthcare expenditure and screening participation was weak and positive ($r = 0.238$), indicating no strong multicollinearity concern. The overall regression model was not statistically significant, $F(1, 22) = 4.03$, $p = 0.057$. The model explained approximately 15% of the variance in breast cancer mortality ($R^2 = 0.15$, Adjusted $R^2 = 0.12$).

Although the predictors collectively accounted for a modest proportion of the variance in mortality, the p-value exceeded the conventional 0.05 significance threshold. Therefore, healthcare expenditure and participation in breast cancer screening did not significantly predict breast cancer mortality in this model. Overall, the findings indicate a weak and statistically non-significant collective effect of healthcare expenditure and screening participation on breast cancer mortality. These findings contribute to a complex and nuanced understanding of the relationships between national healthcare investment, preventive health behaviour and cancer outcomes. The interpretation of these findings benefits from anchoring in two central theoretical frameworks: health systems performance theory and the social determinants of health.

Health systems performance theory proposes that inputs such as financial resources, infrastructure and human capital determine system outputs (e.g., service coverage) and ultimately health outcomes. In this view, higher healthcare expenditure can enhance diagnostic capacity, treatment availability, and chronic disease management, all of which should contribute to lower mortality for conditions like breast cancer. This theoretical premise aligns with work by Frenk (2010), who argue that effective investment in health systems is essential for reducing disease burden. However, the weak predictive power observed in this study suggests that total expenditure by itself may be an insufficient proxy for the aspects of system performance that directly influence mortality. Resource allocation within health systems may not always priorities preventive care or equity in access, especially in contexts where funding is directed towards tertiary services (World Health Organization, 2021). The distinction between health expenditure and health system effectiveness underscores why investment alone, without targeted preventive strategies, may not consistently reduce avoidable deaths.

The social determinants of health framework further posits that factors such as socioeconomic status, education, and cultural norms interact with health system characteristics to shape disease outcomes (Marmot et al., 2008). Within this perspective, screening participation is conceptualized not simply as a function of system provision, but as an outcome of individual and structural determinants, including awareness, affordability, geographic access and perceived utility of preventive services. The directional, albeit statistically non-significant, findings align with a substantial body of literature suggesting that both healthcare resourcing and screening test are important determinants of breast cancer mortality.

Empirical studies in Europe and North America have repeatedly documented lower breast cancer mortality in populations with greater access to well-organized screening programmes and comprehensive treatment pathways (Autier et al., 2010). For example, Autier et al. (2010) found that organized mammography screening implementation was associated with significant mortality reductions among women aged 50-69. Similarly, a pooled analysis by Welch and Passow (2014) indicated that regions with higher screening participation tended to diagnose cancer at earlier stages, leading to better survival outcomes. However, other multinational examinations have shown that variation in breast cancer mortality is only partially explained by screening coverage alone. Paci (2012) demonstrated that socioeconomic disparities, healthcare infrastructure, and follow-up treatment quality moderate the relationship between screening participation and mortality. These findings are consistent with the notion that screening uptake may function more effectively as a mediator between system resources and outcome rather than as a direct predictor. Barriers such as out-of-pocket costs, low health literacy, and cultural attitudes toward medical intervention have been shown to reduce screening uptake even in high-income countries with generous health spending (Li et al., 2025). These studies support the present finding that aggregate healthcare expenditure does not automatically translate into higher participation rates or lower mortality. In lower and middle-income settings, the relationship is even more complex. Thus, health expenditure must be interpreted not just in magnitude but also in terms of distribution across preventive and therapeutic services. From a policy perspective, the present findings reinforce the view that financial investment in health systems must be coupled with targeted interventions to encourage preventive behaviour if meaningful mortality reductions are to be achieved. Simply increasing expenditure without strategic allocation toward preventive care, health promotion and equitable service access is unlikely to produce uniform improvements in outcomes. Although healthcare expenditure and screening participation showed negative correlations with breast cancer mortality and the regression model approached statistical significance, the combined predictive effect was not statistically significant in the present sample. These findings underscore the complexity of the relationships among health system inputs, preventive behaviour, and mortality, and point to the importance of theoretical frameworks such as health systems performance theory and the social determinants of health in interpreting results. The evidence indicates that financial resources must be strategically deployed alongside efforts to enhance screening participation and reduce socioeconomic barriers if reductions in breast cancer mortality are to be realized.

4.20 Multiple regression analysis of the effect of Healthcare expenditure and Participation in cervical cancer screening test on Cervical cancer mortality

Table 30. Multiple regression analysis (x1 *Healthcare expenditure in % of GDP*, x2 *Participation in cervical cancer screening test*, y *Cervical cancer mortality*)

Correlation matrix (pearson)			
	Y	X ₁	X ₂
Y	1	-0.573966	-0.330453
X ₁	-0.573966	1	0.304516
X ₂	-0.330453	0.304516	1

ANOVA table					
Source	DF	Sum of Square	Mean Square	F Statistic	P-value
Regression (between $\hat{y}_i$ and $\bar{y}$)	1	81.972331	81.972331	8.843116	0.00813671
Residual (between y_i and $\hat{y}_i$)	18	166.853169	9.26962		
Total (between y_i and $\bar{y}$)	19	248.8255	13.096079		

Results of the multiple linear regression indicated that there was a **moderate collective significant effect** between the X1, X2, and Y, ($F(1, 18) = 8.84$, $p = 0.008$, $R^2 = 0.33$, $R^2_{adj} = 0.29$).

Pearson correlation coefficients were calculated to examine the bivariate relationships between cervical cancer mortality (Y), healthcare expenditure (X₁), and participation in cervical cancer screening (X₂). Pearson correlation analysis revealed a moderate negative association between cervical cancer mortality and healthcare expenditure ($r = -0.574$), and a weak-to-moderate negative association between mortality and screening participation ($r = -0.330$), indicating that higher health spending and greater screening uptake are associated with lower mortality. The correlation between healthcare expenditure and screening participation was positive but modest ($r = 0.305$), suggesting limited multicollinearity and supporting their inclusion in the regression model.

The multiple linear regression analysis showed a statistically significant collective effect of healthcare expenditure and screening participation on cervical cancer mortality, $F(1, 18) = 8.84$, $p = 0.008$. The model explained 33% of the variance in mortality ($R^2 = 0.33$; Adjusted $R^2 = 0.29$), indicating moderate explanatory power and demonstrating that these predictors jointly contribute meaningfully to differences in cervical cancer mortality across countries. The findings reveal a statistically significant and moderately strong collective association between healthcare expenditure, screening participation, and cervical cancer mortality. The results can be interpreted through the lens of health systems performance theory and the social determinants of health framework. Health systems performance theory conceptualizes health expenditure as a key system input that influences service delivery capacity, quality of care, and ultimately health outcomes (Frenk, 2010). Within this framework, higher healthcare expenditure may enhance infrastructure for primary care, laboratory services, pathology, referral systems, and oncology treatment, all critical components of effective cervical cancer control. However, expenditure alone does not automatically reduce mortality. Its effectiveness depends on how resources are allocated and translated into preventive services and equitable access (World Health Organization, 2020). Cervical cancer is particularly responsive to organized screening systems because it progresses through identifiable precancerous stages. Thus, screening participation operates as an intermediate mechanism linking system resources to reduced mortality.

The social determinants of health framework (Marmot et al., 2008) further emphasizes that preventive service utilization is shaped by socioeconomic position, education, health literacy, cultural norms, and geographic accessibility. Screening participation is therefore both a behavioural outcome and a structural indicator of equity in health service delivery. The moderate explanatory power of the model ($R^2 = 0.33$) suggests that while expenditure and screening are important, broader structural determinants remain influential. Studies comparing European health systems demonstrate that sustained investment in preventive services and primary care correlates with declines in cervical cancer mortality over time (Arbyn et al., 2020). The association between screening participation and reduced mortality is particularly well supported in the literature. Organized cervical cancer screening programmes, especially those using cytology (Pap tests) or HPV testing, have been shown to reduce mortality substantially by detecting precancerous lesions before progression to invasive cancer (IARC, 2016).

Longitudinal evidence from Nordic countries indicates that systematic screening implementation contributed to reductions in cervical cancer mortality of up to 80% over several decades (Vaccarella et al., 2013). Moreover, the effectiveness of screening programmes is highly dependent on coverage and participation rates. Anttila et al. (2009) demonstrate that higher screening coverage is strongly associated with lower incidence of advanced-stage cervical cancer, which directly influences mortality. Thus, the negative correlation observed in the present study between screening participation and mortality is consistent with robust epidemiological evidence. Importantly, research also indicates that the interaction between expenditure and screening infrastructure is critical. Countries with adequate financing but weak programme organization often fail to achieve expected mortality reductions (Ginsburg et al., 2017). This suggests that expenditure must be strategically directed toward organized, population-based screening rather than opportunistic or fragmented services.

The findings have important implications for health policy. First, they reinforce the necessity of sustained investment in health systems, particularly in preventive and primary care services. Second, they demonstrate that financial investment must be accompanied by strategies that maximize screening participation, including:

- Public awareness campaigns
- Removal of financial barriers
- Targeted outreach to underserved populations
- Integration of HPV vaccination and screening strategies

The fact that 67% of the variance in mortality remains unexplained indicates that additional determinants, such as HPV vaccination coverage, socioeconomic inequality, stage at diagnosis, and treatment quality, must be incorporated into future models. Multilevel and longitudinal analyses would further clarify causal pathways and temporal dynamics.

4.21 Multiple regression analysis of the effect of Healthcare expenditure and Participation in colorectal cancer screening test on Colorectal cancer mortality

Table 31. Multiple regression analysis (x1 *Healthcare expenditure in % of GDP*, x2 *Participation in colorectal cancer screening test*, y *Colorectal cancer mortality*)

Correlation matrix (pearson)			
	Y	X ₁	X ₂
Y	1	-0.514769	-0.509592
X ₁	-0.514769	1	0.545184
X ₂	-0.509592	0.545184	1

ANOVA table					
Source	DF	Sum of Square	Mean Square	F Statistic	P-value
Regression (between $\hat{y}_i$ and $\bar{y}$)	1	326.474601	326.474601	6.128836	0.0241189
Residual (between y_i and $\hat{y}_i$)	17	905.566452	53.268615		
Total (between y_i and $\bar{y}$)	18	1232.041053	68.446725		

Results of the multiple linear regression indicated that there was a **moderate collective significant effect** between the X1, X2, and Y, ($F(1, 17) = 6.13$, $p = 0.024$, $R^2 = 0.26$, $R^2_{adj} = 0.22$). Pearson correlation analysis showed that colorectal cancer mortality was moderately and negatively associated with healthcare expenditure ($r = -0.515$) and participation in colorectal cancer screening ($r = -0.510$), indicating that higher health spending and greater screening uptake are linked to lower mortality. Healthcare expenditure and screening participation were positively correlated ($r = 0.545$), though not at a level suggesting problematic multicollinearity.

The multiple regression model demonstrated a statistically significant collective effect of healthcare expenditure and screening participation on colorectal cancer mortality, $F(1, 17) = 6.13$, $p = 0.024$. The model explained 26% of the variance in mortality ($R^2 = 0.26$; Adjusted $R^2 = 0.22$), indicating a moderate and meaningful contribution of these predictors to differences in colorectal cancer mortality across countries. The results demonstrate a moderate and statistically significant collective effect of healthcare expenditure and colorectal cancer screening participation on colorectal cancer mortality. Both predictors are negatively associated with mortality, indicating that higher health investment and greater screening uptake are linked to lower mortality rates. However, as 74% of the variance remains unexplained, additional determinants, such as lifestyle factors, stage at diagnosis, treatment accessibility, and socioeconomic conditions, likely contribute to colorectal cancer mortality patterns. Overall, the findings provide empirical evidence that both health system financing and preventive screening engagement play an important role in shaping colorectal cancer mortality outcomes within the study population. The results demonstrate a statistically significant and moderately strong collective relationship between healthcare expenditure, screening participation, and colorectal cancer mortality. These findings align with theoretical expectations and empirical evidence suggesting that both macro-level health system investment and preventive service utilisation are critical determinants of cancer outcomes.

Colorectal cancer is particularly sensitive to early detection because premalignant polyps can be identified and removed during screening procedures such as colonoscopy or detected through faecal occult blood testing (FOBT). Thus, screening does not merely detect cancer earlier but can prevent cancer development altogether. From a systems perspective, screening participation represents a key output of effective preventive infrastructure, translating financial inputs into measurable health gains. The social determinants of health framework (Marmot et al., 2008) further emphasises that screening uptake reflects broader structural and behavioural factors, including education, income, cultural norms, and health literacy. Even in well-funded systems, participation rates vary significantly across socioeconomic groups (von Wagner et al., 2011).

Therefore, the moderate R^2 (0.26) observed in this model suggests that while system investment and screening participation are important, additional social and behavioural determinants remain influential. The negative association between healthcare expenditure and colorectal cancer mortality observed in this study is consistent with cross-national analyses demonstrating that countries with higher health spending generally achieve better cancer survival outcomes (Allemani et al., 2018). Improved survival has been attributed to earlier diagnosis, timely treatment, and more comprehensive care pathways, factors facilitated by robust health system financing. The relationship between screening participation and reduced mortality is strongly supported in the literature. Randomised controlled trials and population-based evaluations have demonstrated that faecal occult blood testing and colonoscopy screening reduce colorectal cancer mortality by detecting cancers at earlier stages and preventing progression through polypectomy (Hewitson et al., 2008). Long-term observational studies in Europe and North America indicate that organised screening programmes are associated with significant declines in mortality at the population level (Cardoso et al., 2021). Importantly, participation rates are critical for achieving population-level impact. Brenner et al. (2014) showed that higher screening uptake correlates with substantial reductions in advanced-stage disease incidence, directly influencing mortality trends. The moderate negative correlation observed in the present analysis ($r = -0.510$) is therefore consistent with the established evidence base. However, expenditure alone does not guarantee equitable participation; targeted outreach and policy design remain critical. Although the regression model was statistically significant, it explained 26% of the variance in colorectal cancer mortality. This indicates that nearly three-quarters of the variation remains attributable to other determinants. Potential contributing factors include:

- Lifestyle risk factors (e.g., diet, obesity, alcohol consumption, physical inactivity)
- Stage at diagnosis
- Access to specialised oncology treatment
- Surgical quality and post-treatment care
- Socioeconomic inequalities
- Public health policy differences

Colorectal cancer is strongly influenced by behavioural risk factors, which may dilute the observable effect of screening and expenditure alone (Arnold et al., 2017). Furthermore, treatment advancements, such as improved surgical techniques and adjuvant therapies, also significantly affect mortality trends, independent of screening participation. Thus, the moderate explanatory power of the model reflects the multifactorial nature of colorectal cancer mortality. Screening and expenditure are important, but they operate within a broader ecological system of determinants. The findings underscore the importance of integrated cancer control strategies that combine:

1. Adequate and sustained healthcare financing
2. Organised, population-based screening programmes
3. Public engagement strategies to maximise participation
4. Equitable access to high-quality treatment

Policy approaches focusing solely on increasing health expenditure without strengthening screening infrastructure and addressing participation barriers may not achieve optimal mortality reductions. Conversely, screening programmes without sufficient funding and follow-up capacity may fail to deliver sustainable benefits. The statistically significant collective effect observed in this study supports investment in preventive services as a cost-effective strategy for reducing colorectal cancer mortality. However, comprehensive approaches addressing behavioural risk factors and treatment equity are also necessary. In conclusion, the regression analysis demonstrates a moderate and statistically significant collective effect of healthcare expenditure and colorectal cancer screening participation on colorectal cancer mortality ($F(1, 17) = 6.13, p = 0.024; R^2 = 0.26$). Both predictors are negatively associated with mortality, consistent with theoretical expectations and extensive empirical evidence on the effectiveness of screening and health system investment. While these findings confirm the importance of preventive engagement and health system capacity, they also highlight the multifactorial determinants of colorectal cancer mortality. Future research incorporating longitudinal and multilevel approaches may further clarify causal pathways and the interaction between structural, behavioural, and clinical determinants.

4.21.1 Comparative statistical findings

Across the three cancer types, healthcare expenditure and screening participation were negatively correlated with mortality; however, the strength and statistical significance of the regression models differed.

- Breast cancer: The model approached but did not reach statistical significance ($p = 0.057$; $R^2 = 0.15$), indicating a weak collective effect.
- Cervical cancer: The model was statistically significant ($p = 0.008$; $R^2 = 0.33$), demonstrating a moderate explanatory effect.
- Colorectal cancer: The model was statistically significant ($p = 0.024$; $R^2 = 0.26$), indicating moderate explanatory power.

The proportion of explained variance was highest for cervical cancer (33%), followed by colorectal cancer (26%), and lowest for breast cancer (15%). This pattern suggests that healthcare expenditure and screening participation are more strongly associated with mortality in cancers where screening plays a direct preventive role.

Cervical and colorectal cancers are characterised by identifiable and treatable precancerous stages. Screening in these cancers (e.g., Pap/HPV testing and colonoscopy) enables not only early detection but also primary prevention through removal or treatment of premalignant lesions (IARC, 2016; Hewitson et al., 2008). Consequently, screening participation has a stronger and more direct pathway to mortality reduction. This helps explain the higher R^2 values observed in Sections 4.20 and 4.21.

In contrast, breast cancer screening primarily facilitates earlier detection rather than prevention. Although early-stage diagnosis improves survival, it does not prevent cancer occurrence. Mortality outcomes in breast cancer are also strongly influenced by tumour biology, treatment advancements, and systemic therapies (Allemani et al., 2018). Therefore, the weaker and non-significant collective effect observed for breast cancer reflects the more complex and multifactorial nature of mortality determinants in that disease.

Results for cervical and colorectal cancer suggest that where preventive infrastructure is well-established and biologically effective, financial investment may translate more efficiently into mortality reductions. The comparative regression analyses reveal a consistent negative association between healthcare expenditure, screening participation, and cancer mortality across breast, cervical, and colorectal cancers. However, the magnitude and statistical strength of these relationships vary by cancer type, reflecting differences in disease biology, screening effectiveness, and treatment dynamics. Cervical cancer demonstrated the strongest association, followed by colorectal cancer, while breast cancer showed a weaker collective effect. These differences align with theoretical expectations regarding the preventive potential of screening and the pathways linking health system investment to mortality outcomes. Overall, the findings support a multidimensional model of cancer control in which financial investment, preventive service uptake, and broader structural determinants jointly shape population health outcomes. Future research employing longitudinal and multilevel designs would further clarify causal pathways and strengthen policy translation.

4.22 Business-related solutions and recommendations for the healthcare industry

The global healthcare industry is a >\$4 trillion sector in which artificial intelligence is expected to generate significant savings. The healthcare industry can certainly be observed through the prism of business opportunities as well. As an industry, it has grown significantly over the past decades due to technological advances in various domains (manufacturing, supply chains, international trade, etc.). The European healthcare industry particularly, is undergoing a rapid digital transition. According to Eurostat (2025), the total healthcare expenditure which reflects the overall size of the healthcare market in terms of spending on health services and goods in the European Union, reached approximately €1 720 billion in 2023. However, it is necessary to understand the areas of expenditure for the purpose of further improvement: services/facilities (hospitals, clinics), research, devices, pharmaceuticals, biotech, and care/insurance. While private equity and investors are increasingly entering the market, specific business recommendations for healthcare industry in both cancer and cardiovascular disease prevention are elaborated below.

4.23 Business-related recommendations for healthcare industry in cancer prevention

Cancer is a major societal, public health, and economic problem in the 21st century, responsible for almost one in six deaths (16.8%) and one in four deaths (22.8%) from noncommunicable diseases worldwide (Bray et al., 2024). Empirical findings of this research indicate a strong collective significant effect of GDP and participation in colorectal cancer screening test to total colorectal cancer mortality among the EU countries; a moderate collective significant effect of national healthcare expenditure and participation in cervical cancer screening test to total cervical cancer mortality among the EU countries; and a moderate collective significant effect national healthcare expenditure and participation in colorectal cancer screening test to total colorectal cancer mortality among the EU countries. Investments in prevention, including the targeting of key risk factors for cancer (including smoking, obesity, and infections), can avert millions of future cancer diagnoses and save many lives worldwide (Soerjomataram and Bray, 2021). From a market perspective, cancer screening is embedded within preventive healthcare business models that prioritize continuity of care, data-driven risk stratification, and long-term customer engagement.

According to Cohen et al. (2018) earlier detection is key to reducing cancer deaths. Early detection technologies including cancer screening, are lowering entry barriers for private providers and startups. De Koning et al. (2020) in their trial involving high-risk persons showed that lung-cancer mortality was significantly lower among those who underwent volume CT screening than among those who underwent no screening. There were low rates of follow-up procedures for results suggestive of lung cancer. Simple cost-effectiveness analyses demonstrate that targeted screening reduces long-term expenditures for insurers and governments, particularly when integrated with digital follow-up and behavioral nudging platforms. Given high sensitivities and specificities multi cancer early detection (MCED) tests show promise as additional screening tools. Although multiple barriers to its application in the clinic exist, MCED tests may improve patient outcomes for cancers with no conventional screening tool, and provide additional credibility when used in combination with existing tools (Park et al., 2023). The commercial appeal of MCED technologies stems from their promise to detect multiple cancer types from a single blood draw, often before symptoms arise, thereby expanding the addressable market far beyond single-organ screening programs.

Despite the opportunities, healthcare providers face challenges in implementing obesity-focused and tobacco cessation strategies. Counseling, behavior therapy, medicines, and nicotine-containing products, may be used to help a person quit smoking. Tobacco cessation can be also positioned as a strategic business initiative with both direct and indirect benefits in terms of cancer prevention and treatment. According to the Union for International Cancer Control and Bupa (2015), for businesses, even if they have non-smoking workplaces, helping employees quit smoking can improve their bottom line through avoiding lost productivity and absences due to sickness, reducing healthcare costs, and avoiding lost productivity due to people taking smoking breaks. Supporting employees to quit smoking should be part of investing in a broader healthy workplace culture which promotes employee engagement, organizational productivity, talent retention, and creativity and innovation. In many companies today, especially in the Far East, such company initiatives are almost commonplace because tobacco cessation may serve as a corporate social responsibility tool. This makes cessation initiatives a cost-effective intervention, offering a tangible return on investment in a broader sense. This approach is particularly effective in healthcare itself but also in healthcare-related sectors like insurance, hospitality, kinesiology, biotech, etc.

WHO/UNICEF estimates for Human papillomavirus infection (HPV) vaccination coverage from 2010 to 2019 are analyzed against the backdrop of the 90% coverage target for HPV vaccination by 2030 set in the recently approved global strategy for cervical cancer elimination as a public health problem (Bruni et al., 2021). From a healthcare business perspective, marketing these vaccines as cancer prevention tools aligns with the growing trend of preventive, value-based care. Digital campaigns, bundled preventive health packages, and integration with routine pediatric and adult care visits can amplify reach and adherence. Ethical marketing requires transparent communication: while vaccines are highly effective, they are not substitutes for regular screenings or other preventive behaviors. When implemented thoughtfully, a business model that emphasizes vaccines as direct cancer prevention aligns patient health incentives with sustainable revenue streams, positioning healthcare providers at the intersection of innovation, prevention, and patient trust.

Partnering with employee resource groups (ERGs) for culturally sensitive, targeted cancer outreach may serve as a pragmatic strategy to address persistent inequities in cancer prevention, screening uptake, and early detection. Public health and organizational health scholars argue that these groups can function as effective intermediaries between health systems, employers, particularly in prevention-oriented cancer initiatives. ERGs, by virtue of shared identity and social capital, are uniquely positioned to contextualize cancer risk, prevention, and screening narratives in ways that align with cultural norms and lived experience. The workplace itself is increasingly recognized as a critical setting for cancer prevention delivery. ERG partnerships enhance these programs by facilitating co-designed outreach campaigns and culturally relevant framing of emerging technologies such as genetic testing, AI-based risk assessment, and multi cancer early detection. Emerging scholarship also situates ERG partnerships within broader business and health system strategies. In this framing, ERGs are not merely outreach channels but strategic partners in designing scalable, trust-based cancer prevention ecosystems that integrate education, screening access, and follow-up navigation. In contrast to traditional screening paradigms that rely on fixed intervals and single modality tests, AI enabled early warning leverages longitudinal data streams, including imaging, genomics, electronic health records, wearable data, and lifestyle indicators in order to identify subtle preclinical signals of malignancy. High-impact oncology and digital health research emphasizes that this shift enables earlier intervention windows, particularly for cancers that currently lack effective population screening strategies, such as pancreatic, ovarian, and liver cancers (Topol, 2019).

Within imaging based early warning, AI driven pattern recognition has demonstrated clinically meaningful gains in sensitivity and specificity across breast, lung, colorectal, and prostate cancers. Deep learning models applied to mammography, low-dose CT, and histopathology slides are shown to detect malignancy-associated features that precede radiologist recognition, effectively functioning as warning layers rather than diagnostic endpoints. According to Hosny et al. (2018) methods ranging from convolutional neural networks to variational autoencoders have found myriad applications in the medical image analysis field, propelling it forward at a rapid pace. Historically, in radiology practice, trained physicians visually assessed medical images for the detection, characterization and monitoring of diseases. AI methods excel at automatically recognizing complex patterns in imaging data and providing quantitative, rather than qualitative, assessments of radiographic characteristics. Additionally, predictive performance improves with scale and diversity of data, incentivizing partnerships between technology firms, health systems, diagnostics companies, and insurers. According to Rajkomar et al. (2019), the accelerating creation of vast amounts of healthcare data will fundamentally change the nature of medical care while the patient-doctor relationship will be the cornerstone of the delivery of care to many patients and that the relationship will be enriched by additional insights from machine learning. Also, with expectations a handful of early models and peer-reviewed publications of their results to appear in the next few years which, along with the development of regulatory frameworks and economic incentives for value-based care, are reasons to be cautiously optimistic about machine learning in health care.

High-performance computing (HPC) is framed as a foundational enabler of scale, speed, and integration across early detection, risk prediction, and population-level surveillance. Unlike conventional computing infrastructures, HPC allows simultaneous processing of massive, heterogeneous datasets, genomics, imaging, electronic health records, environmental exposures, and longitudinal lifestyle data, making it central to prevention-oriented oncology rather than solely treatment-focused research. Cancer prevention has become a computational problem as much as a biological one, with HPC acting as the backbone that translates complex data into actionable early warning and screening strategies (Topol, 2019). In genomic and molecular prevention research, HPC enables large-scale analysis of whole-genome sequencing, epigenomics, and circulating tumor DNA signals at population scale. Some capabilities underpin multi-cancer early detection and polygenic risk modeling, reframing prevention as a continuous, data-intensive process rather than a series of discrete tests. HPC also plays a critical role in imaging-based cancer prevention through AI model training and deployment.

Deep learning systems for mammography, low-dose CT, colonoscopy, and digital pathology rely on HPC clusters and GPUs to process petabyte-scale image repositories and iteratively refine predictive performance. Also, HPC-supported models can identify pre-malignant patterns and long-term risk trajectories, enabling adaptive screening intervals and targeted surveillance strategies that reduce both overdiagnosis and missed early disease (Ardila et al., 2019). In this context, HPC is not merely a technical asset but a determinant of clinical feasibility and scalability. At the population health level, HPC facilitates large-scale cancer prevention modeling and simulation. Epidemiological studies show that microsimulation models used to evaluate screening strategies, AI-enabled early warning systems, and policy interventions, depend on HPC to explore millions of hypothetical scenarios across diverse populations. These models inform national cancer control strategies and reimbursement decisions, linking HPC directly to preventive policy and health system planning. From a translational and commercial perspective, the literature increasingly positions HPC as a strategic asset for preventive oncology platforms.

Cloud-based HPC infrastructures allow startups and health systems to deploy scalable prevention services, including AI-driven risk monitoring, multi cancer screening analytics, and real time decision support. Digital tools have increasingly become central to risk awareness and scalable interventions in cancer prevention, particularly as healthcare systems face the dual challenges of rising cancer incidence and cost containment. Mobile health applications, wearable devices, and AI driven platforms have been leveraged to facilitate early detection, personalized risk assessment, and behavior modification strategies. Deep learning, a subfield of machine learning, has seen a dramatic resurgence in the past years, largely driven by increases in computational power and the availability of massive new datasets (LeCun et al., 2015). Deep-learning models scale to large datasets in part owing to their ability to run on specialized computing hardware, and continue to improve with more data, enabling them to outperform many classical machine learning approaches.

Deep-learning systems can accept multiple data types as input, an aspect of particular relevance for heterogeneous healthcare data (Esteva et al., 2019). Key business drivers include patient engagement and retention, scalability across diverse populations, and regulatory compliance. Market analyses suggest that investments in digital prevention tools are growing in line with broader digital health funding trends, with a notable emphasis on platforms that can demonstrate measurable population-level impact and integration with existing electronic health records.

Fogel and Kvedar (2018) concluded even, as repetitive tasks are automated, humans will be able to focus on the tasks that are uniquely human: building relationships, exercising empathy, and using human judgment to guide and advise while perhaps AI will enable healthcare to be more human. Business strategies that emphasize interoperability, patient trust, and outcomes-based partnerships with insurers can significantly enhance market uptake. Digital platforms also facilitate scalable behavior-change interventions for cancer prevention, targeting modifiable risk factors such as smoking, diet, and physical activity. Evidence from behavior-change apps indicates improved engagement and health literacy, which indirectly strengthens brand credibility and customer loyalty for healthcare providers offering such services. Developing and evaluating these digital interventions presents new challenges and new versions of old challenges that require use of improved and perhaps entirely new methods for research and evaluation (Michie et al., 2017). From a strategic standpoint, integrating predictive analytics with user-centric design enhances both efficacy and commercial viability, creating a feedback loop between clinical value and business performance (Topol, 2019).

Table 32. Tools that analyze patient history, lifestyle, and genetic data to predict the likelihood of developing cancer (author's summary based on existing market solutions)

Tool/Model	Description
CATCH-FM	A tool that utilizes electronic health record (HER) data to predict cancer risk.
Generative AI for Health Forecasting	Model trained on 400,000 UK Biobank participants to predict risk and timing of diseases.
CanPredict (Lung)	Model validated on nearly 20 million people to predict future lung cancer risk.
Machine Learning (ML) on Lifestyle Factors	Algorithms analyze lifestyle behaviors and genetic profiles for personalized risk scores.
Clarity Breast Cancer Risk	Platform that analyzes mammograms to predict 5-year breast cancer risk.
Google Health (LYNA)	Uses deep learning to analyze pathology slides to detect metastasis in lymph nodes.
Mia (Breast Screening)	AI solution to identify small signs of breast cancer in mammograms.
ColonFlag®	AI tool that analyzes blood test results to predict colorectal cancer risk.
AI-Assisted Colonoscopy/Endoscopy	Deep CNN algorithms used to detect polyps or precancerous lesions.
Liquid Biopsy (LB) & Genomics	AI processes data from blood tests for early, noninvasive detection of ctDNA.
Nurse AMIE	Tablet-based virtual assistant that helps manage symptoms in cancer patients.

4.24 Business-related recommendations for healthcare industry in cardiovascular diseases prevention and treatment

Early detection for cardiovascular diseases (CVD) is framed as a high-potential business opportunity, driven by the convergence of epidemiologic burden, technological innovation, and value-based healthcare incentives. Globally, CVD remains the leading cause of mortality. From a technology perspective, innovations in AI-enabled risk prediction, multi-modal diagnostics, and wearable devices are key drivers of commercial potential. AI algorithms applied to electronic health records, imaging, and continuous physiologic data enable precise stratification of individuals by CVD risk, guiding personalized screening intervals and preventive interventions. Application of AI to the ECG—a ubiquitous, low-cost test—permits the ECG to serve as a powerful screening tool in asymptomatic individuals to identify ALVD (Attia et al., 2019). Wearable technologies, including smartwatches, patches, and biosensor-enabled clothing, extend early detection into continuous, remote monitoring, increasing adherence and engagement while generating real-world longitudinal datasets that further improve predictive models. Also, Tison et al. (2018) showed that a commercially available smartwatch can passively identify AF against the criterion-standard 12-lead ECG among sedentary individuals when heart rate data are collected at a high temporal resolution. They presented an exploratory analysis demonstrating that deep neural network substantially outperforms standard techniques to detect self-reported persistent AF from ambulatory data, albeit with modest accuracy in these free-living natural environments. Given the broad and growing use of smartwatches and ready accessibility of downloadable mobile applications, this approach may ultimately be applied to perform AF detection at large scale, ultimately leveraging common wearable devices to guide AF management and rhythm assessment.

The business potential of CVD early detection is reinforced by health economics and payer incentives. Employers, insurers, and health systems can monetize preventive programs through direct-to-consumer subscriptions, employer wellness platforms, integration with electronic health records, and partnerships with diagnostic and telehealth companies. Market segmentation analyses suggest multiple scalable business pathways. Employer or health system-based programs leverage ERG or population health strategies to increase engagement and equity, particularly among high-risk or underserved populations.

Commercial partnerships with laboratories and imaging providers enable hybrid screening models, combining in-person diagnostics with remote monitoring for longitudinal risk assessment. Ethical, regulatory, and adoption considerations are central to commercial success. Programs that integrate culturally sensitive education, digital literacy support, and insurance coverage are positioned to achieve both health impact and market penetration. Partnering with employers to prevent cardiovascular diseases is increasingly recognized as a strategic and impactful approach, leveraging the workplace as a platform for scalable, population-level prevention while simultaneously aligning with corporate wellness, productivity, and ESG goals. The workplace provides unique advantages for prevention: access to a defined population, the ability to integrate interventions into daily routines, and the opportunity to leverage organizational resources for health promotion. Employer partnerships allow for multi-tiered intervention strategies, ranging from on-site screenings and health coaching to remote monitoring via wearables and AI-driven risk stratification, facilitating both primary and secondary prevention. Employee Resource Groups (ERGs) and culturally tailored outreach enhance program engagement, particularly among underrepresented groups. From a business and health economics perspective, employer driven CVD prevention programs yield tangible benefits. These initiatives can be structured as part of value-based health strategies, wellness incentives, or partnerships with payers and digital health startups, creating new business opportunities for both employers and health technology companies. Employer partnerships also enable data-driven population health management. Aggregated, de-identified employee data from screenings, wearable devices, and health apps can inform predictive models of CVD risk, guide targeted interventions, and support continuous improvement in program effectiveness. Critical considerations include privacy, equity, and ethical use of employee health data. Long-term success is linked to co-designed programs, integration with existing benefits, and continuous evaluation of health and economic outcomes.

Digital health tools are recognized as transformative for cardiovascular disease (CVD) prevention and treatment, enabling personalized risk management, continuous monitoring, and scalable interventions that extend beyond traditional clinical encounters. These tools encompass a spectrum of technologies, including mobile health apps, wearable sensors, telemedicine platforms, remote patient monitoring (RPM), and AI-driven predictive analytics, all of which support primary, secondary, and tertiary prevention strategies.

The literature emphasizes that CVD, responsible for over 17 million deaths annually worldwide, is particularly well-suited to digital interventions because of its strong link to modifiable risk factors, chronic disease management needs, and the availability of continuous biometric and behavioral data (Virani et al., 2021). Mobile apps and wearable devices facilitate primary prevention by providing personalized feedback on lifestyle behaviors such as physical activity, diet, and sleep, alongside real-time biometrics like heart rate, blood pressure, and ECG signals. AI-enhanced apps can further stratify risk, predict arrhythmic events, and detect early signs of decompensation, allowing clinicians to intervene proactively. Telemedicine and RPM platforms have accelerated adoption, particularly in secondary prevention for patients with heart failure, post-myocardial infarction, or post-procedural monitoring. Integration of AI and predictive analytics is a major trend in digital cardiovascular health. Machine learning models applied to continuous physiological data and electronic health records enable early identification of individuals at high risk for myocardial infarction, stroke, or heart failure exacerbation. From a population health and business perspective, digital health tools are positioned as both cost-effective and scalable. Health economic analyses suggest that smartphone apps, RPM, and AI driven interventions reduce long-term CVD burden by lowering hospitalization rates and improving adherence to guideline-directed therapies.

Wearable technology for cardiovascular health monitoring has emerged as a major focus in both clinical research and digital health commercialization, offering continuous, real-time insights into key physiologic parameters and enabling personalized, proactive management of cardiovascular risk. These devices, ranging from smartwatches and chest patches to biosensor-enabled clothing, capture metrics such as heart rate, heart rate variability, blood pressure, oxygen saturation, ECG, and physical activity, providing a continuous digital phenotype of cardiovascular function. Clinical studies demonstrate that wearables can reliably detect arrhythmias such as atrial fibrillation, track trends in heart rate and blood pressure, and even signal early decompensation in heart failure patients. For example, AI enhanced smartwatches can analyze photoplethysmography and ECG data to identify irregular rhythms with high sensitivity, providing actionable alerts that prompt timely medical evaluation. Wearables also integrate into larger digital health ecosystems, enabling remote patient monitoring (RPM) and telemedicine applications.

Data from devices can feed into clinician dashboards, alerting care teams to early warning signs and allowing interventions without in-person visits. Studies indicate that such integration reduces hospital readmissions, improves medication adherence, and supports personalized cardiovascular care plans. Multi-parametric devices that combine heart rate, ECG, and activity monitoring are particularly suited to long-term risk stratification, guiding both preventive and therapeutic decision-making. From a business and implementation perspective, wearable solutions for cardiovascular health are attractive because they align patient engagement, continuous monitoring, and AI-driven analytics into scalable platforms. The integration of Clinical Decision Support Systems (CDSS) with AI is emerging as a transformative approach in both the prevention and treatment of cardiovascular diseases (CVD), offering opportunities to improve early detection, personalize interventions, and optimize healthcare delivery. In primary prevention, AI-enhanced CDSS can stratify cardiovascular risk more accurately than conventional scoring systems like the Framingham Risk Score or ASCVD calculator. By analyzing complex, multidimensional data, including electronic health records, genomics, wearable derived physiologic metrics, lab values, and lifestyle data, AI algorithms embedded in CDSS can identify high risk individuals who may benefit from targeted interventions such as statin therapy, antihypertensives, or lifestyle modification programs. Studies demonstrate that AI-driven CDSS can predict adverse events such as myocardial infarction, atrial fibrillation, or heart failure exacerbation with higher sensitivity and specificity than traditional risk models, facilitating earlier preventive action. A critical benefit of this integration is personalization of care. AI algorithms can tailor recommendations to individual patient characteristics, including comorbidities, demographics, genetic risk factors, and behavioral patterns. Furthermore, CDSS integrated with AI can continuously learn from patient outcomes and real data, improving predictive accuracy over time, which is particularly valuable for chronic conditions like hypertension, heart failure, and atrial fibrillation. Ethical and equity considerations are also highlighted, ensuring that AI-CDSS tools do not exacerbate disparities in cardiovascular outcomes across different demographic and socioeconomic groups. In conclusion, the biotech industry, supported by increasingly capable artificial intelligence in the field of prevention and monitoring of cardiovascular diseases, is opening up more business opportunities than ever before.

Table 33. Cardiovascular Monitoring & Prevention Apps (author's summary based on existing market solutions)

App Name	Description
KardiaMobile (AliveCor)	A highly regarded, FDA-cleared personal EKG monitor that pairs with an app to detect atrial fibrillation (AFib) and normal heart rhythm in 30 seconds.
FibriCheck	A medically certified (FDA/CE) app that uses the smartphone camera to measure heart rhythm and detect irregularities like AFib.
Qardio Heart Health	Pairs with Qardio's blood pressure monitors to track blood pressure, heart rate, and weight, offering detailed visualizations of trends.
Hello Heart	A HIPAA-compliant app tailored for managing blood pressure and hypertension, providing daily insights to help reduce risks of heart attack and stroke.
SmartBP (Smart Blood Pressure)	A dedicated, user-friendly app for recording, tracking, and analyzing blood pressure, pulse, and weight, with features to export reports for doctors.
Cardiio	Uses the smartphone camera to measure heart rate, providing insights into resting heart rate and cardiovascular endurance.
ASCVD Risk Estimator Plus	Developed by the American College of Cardiology to help assess the 10-year risk of atherosclerotic cardiovascular disease.

4.25 Summary of Findings

Some of the key findings indicate a strong collective significant effect of GDP and participation in colorectal cancer screening test to total colorectal cancer mortality among the EU countries; a moderate collective significant effect of national healthcare expenditure and participation in cervical cancer screening test to total cervical cancer mortality among the EU countries; a moderate collective significant effect national healthcare expenditure and participation in colorectal cancer screening test to total colorectal cancer mortality among the EU countries. Also, valuable research-based business-related recommendations for healthcare industry were provided in terms of early detection technology, wearables technology, tobacco cessation, obesity management, commercial partnerships, partnerships with employee resource groups, high-performance computing, and increased AI-driven solutions.

CHAPTER V:

CONCLUSION, IMPLICATIONS, AND RECOMMENDATIONS

There is complex association of GDP, national healthcare expenditure and participation in national cancer screening programmes with mortality from cancer and cardiovascular diseases in the EU countries. Some of the key findings indicate a strong collective significant effect of GDP and participation in colorectal cancer screening test to total colorectal cancer mortality among the EU countries; a moderate collective significant effect of national healthcare expenditure and participation in cervical cancer screening test to total cervical cancer mortality among the EU countries; a moderate collective significant effect national healthcare expenditure and participation in colorectal cancer screening test to total colorectal cancer mortality among the EU countries. Also, valuable research-based business-related recommendations for healthcare industry were provided in terms of early detection technology, wearables technology, tobacco cessation, obesity management, commercial partnerships, partnerships with employee resource groups, high-performance computing, and increased AI-driven solutions.

This study highlights the significant role that economic performance, public health initiatives and health outcomes play in shaping population's health, particularly within the diverse context of the European Union. Those relationships reveal insights into the effectiveness and impact of health policies and interventions in different EU countries. Since GDP plays a fundamental role in shaping health budgets, service availability and the development of public health strategies, its impact on cancer screening and CVD mortality cannot be underestimated. Higher GDP generally correlates with better health infrastructure and increased access to health services, thereby potentially increasing the effectiveness of public health interventions such as cancer screening programs. These programs have been proven to reduce mortality through early detection, particularly for cancers such as breast, cervical and colorectal cancer. Cardiovascular diseases remain the leading cause of death and disease in the EU, and multiple risk factors such as hypertension, smoking, obesity and poor diet contribute significantly to their prevalence.

Although GDP may affect the overall quality and availability of health services, the direct relationship between economic performance, success of cancer screening programs, and cardiovascular disease mortality requires further investigation. The studies' findings suggest that while economic growth is associated with better health systems, other factors, including health policies, health care equity and preventive measures, also play a key role in reducing cardiovascular disease mortality. By analyzing the dynamic relationships between mentioned variables, this research may provide valuable insights for future health policies and economic strategies. It has a potential to the need for a comprehensive approach that combines economic development with targeted public health interventions, especially those aimed at cancer prevention and cardiovascular disease reduction.

This study has several limitations: cross-sectional design while the analysis relies on a single point in time, limiting causal inference; use of country-level data does not account for individual-level factors or within-country variability; covariates such as stage at diagnosis, treatment uptake, and genetic factors were unavailable. Future studies should address these limitations by incorporating multilevel, longitudinal datasets and adjusting for confounding variables to clarify the relationship between screening participation and breast cancer mortality.

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