Technical and Scale Efficiency of Public Hospitals in Papua New Guinea

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การวัดประสิทธิภาพทางด้านเทคนิคและประสิทธิภาพขนาดของโรงพยาบาลของรัฐในประเทศปาปัวนิวกินี

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วิทยานิพนธ์นี้เป็นส่วนหนึ่งของการศึกษาตามหลักสูตรปริญญาวิทยาศาสตรมหาบัณฑิต
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เจมส์ โนอา : การวัดประสิทธิภาพทางด้านเทคนิคและประสิทธิภาพขนาดของโรงพยาบาลของรัฐในประเทศปาปัวนิวกินี. (Technical and Scale Efficiency of Public Hospitals in Papua New Guinea) อ.ที่ปรึกษาหลัก : ศ.ศิริเพ็ญ ศุภกาญจนกันติ

การศึกษานี้มีวัตถุประสงค์เพื่อประเมินค่าประสิทธิภาพเชิงเทคนิคแบบสัมพัทธ์ของโรงพยาบาลรัฐในประเทศปาปัวนิวกินี และประเมินถึงการเพิ่มผลผลิตและลดปัจจัยการผลิตเท่าไรจึงจะทำให้โรงพยาบาลที่ไม่มีประสิทธิภาพเชิงเทคนิคแบบสัมพัทธ์สามารถดำเนินงานได้อย่างมีประสิท ธิภาพเพิ่มขึ้น โดยใช้วิธีวิเคราะห์เชิงโอบล้อมข้อมูล หรือ DEA ซึ่งใช้โมเดล BCC มีข้อมูลโรงพยาบาล 20 แห่ง เป็นข้อมูลในปี ค.ศ. 2017 การศึกษานี้ได้ใช้การวิเคราะห์การถดถอยโทบิท (Tobit regression) เพื่อวิเคราะห์ปัจจัยต่างๆทั้งปัจจัยเชิงสถาบันและเชิงบริบท ที่ส่งผลต่อประสิทธิภาพโรงพยาบาล ผลการศึกษาโดยใช้แบบจำลอง DEA BCC ทางด้านผลผลิต ชี้ให้เห็นว่าภายใต้ข้อสมมติของการมีผลได้ต่อขนาดคงที่ ค่าเฉลี่ยของประสิทธิภาพเชิงเทคนิคคือ 79% ภายใต้ข้อสมมติแบบผลได้ต่อขนาดแปรผัน ค่าเฉลี่ยของประสิทธิภาพเชิงเทคนิค คือ 92% และค่าเฉลี่ยของประสิทธิภาพขนาด คือ 86%

โรงพยาบาลที่ไม่มีประสิทธิภาพสามารถปรับปรุงให้มีประสิทธิภาพได้ โรงพยาบาลที่ไม่มีประสิทธิภาพ 7แห่งจำเป็นต้องเพิ่มการบริการคนไข้นอก 31% และคนไข้ใน 27% จึงจะมีประสิทธิภาพ และอีกทางเลือกหนึ่งโรงพยาบาลที่ไม่มีประสิทธิภาพสามารถปรับปรุงให้มีประสิทธิภาพแบบสัมพัทธ์ ได้โดยการลดจำนวนเตียงลง 19% จำนวนแพทย์ 34% พยาบาล 13% และบุคลากรอื่นๆ 31% สำหรับรูปแบบประสิทธิภาพขนาดแสดงได้ว่าจากโรงพยาบาลที่ไม่มีประสิทธิภาพ 7 แห่ง มีโรงพยาบาลอยู่ 2 แห่งที่ดำเนินงานภายใต้รูปแบบผลได้ต่อขนาดเพิ่มขึ้น โดยมีโรงพยาบาล 5 แห่งที่ดำเนินงานภายใต้ผลได้ต่อขนาดลดลง

สำหรับการศึกษานี้มุ่งที่ประเด็นการประเมินคะแนนประสิทธิภาพเชิงเทคนิคและประสิทธิภาพขนาด ซึ่งสามารถใช้สำหรับการวางแผนโรงพยาบาลและนโยบายการบริหาร ผลลัพธ์จากแบบจำลองถดถอยโทบิท ชี้ให้เห็นว่าอัตราส่วนเตียงต่อพยาบาล (RoBTN) มีความสัมพันธ์เชิงบวกอย่างมีนัยสำคัญ กับคะแนนความไม่มีประสิทธิภาพ หรืออีกนัยหนึ่ง RoBTN เพิ่มขึ้นหนึ่งหน่วย จะทำให้ความไม่มีประสิทธิภาพของโรงพยาบาลเพิ่มขึ้น 19% มีข้อสังเกตว่าการเพิ่มจำนวนพยาบาลสำหรับจำนวนเตียงที่มีอยู่ จะลดความไม่มีประสิทธิภาพอย่างมีประสิทธิผล นอกจากนั้น อัตราส่วนเตียงต่อแพทย์ (RoBTD) มีความสัมพันธ์เชิงลบอย่างมีนัยสำคัญ หมายถึงจำเป็นต้องลดจำนวนแพทย์ที่มีอยู่เพื่อจะลดความไม่มีประสิทธิภาพให้ลดลง นั่นคือจำเป็นต้องมีแนวทางที่ดีกว่าและมีนโยบายในการบริหารโรงพยาบาลให้มีประสิทธิภาพโดยการจัดสรรและโยกย้ายแพทย์ เพื่อโรงพยาบาลจะได้มีประสิทธิภาพที่ดีขึ้น โรงพยาบาลรัฐที่มีจำนวนเตียงที่มากจะมีความสัมพันธ์เชิงลบอย่างมีนัยสำคัญกับความไม่มีประสิทธิภาพของโรงพยาบาล นั่นคือ ควรให้คำแนะนำถึงการทำให้จำนวนเตียงเพิ่มขึ้นแล้วจะทำให้ความไม่มีประสิทธิภาพลดลงและส่งผลให้การบริการสุขภาพมีประสิทธิผล

นโยบายการปรับปรุงโรงพยาบาลรัฐมีความเชื่อมโยงกับการจัดสรรทรัพยากรทั้งภายในและระหว่างโรงพยาบาลได้หลากหลายแนวทาง บางอย่างสะท้อนถึงอุปสงค์ต่อบุคลากรทางการแพทย์ และบางอย่างสะท้อนถึงอุปทานของประเภทและทักษะ ความเชี่ยวชาญของบุคลากรทางการแพทย์ ผลลัพธ์ของการศึกษาแสดงถึงบางส่วนของความเป็นไปได้ในการเลือกองค์ประกอบของแผนการบริหารโรงพยาบาลเท่านั้น มีผลกระทบมากมายและหลากหลาย ไม่ว่าจะเป็นผลกระทบทางตรงที่ใช้กำหนดนโยบาย ผลกระทบทางอ้อม หรือผลกระทบอย่างมีเงื่อนไขทั้งทางตรง ทางอ้อม ซึ่งจะแปรไปตามองค์ประกอบและรายละเอียดของแผน ดังนั้นจึงไม่มีการกล่าวถึงคำแถลงทั่วไปเกี่ยวกับการเชื่อมโยงการปรับปรุงโรงพยาบาลที่ไม่มีประสิทธิภาพกับผลการวิเคราะห์เชิงทฤษฎีเกี่ยวกับคะแนนประสิทธิภาพเชิงเทคนิคและประสิทธิภาพขนาดแต่เพียงอย่างเดียวเท่านั้น การแปลผลการค้นพบสำหรับข้อแนะนำเชิงนโยบายควรกระทำด้วยความระมัดระวัง

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KEYWORD: TECHNICAL EFFICIENCY DATA ENVELOPMENT ANALYSIS PUBLIC HOSPITALS TOBIT REGRESSION ANALYSIS

James Noah : Technical and Scale Efficiency of Public Hospitals in Papua New Guinea. Advisor: Prof. SIRIPEN SUPAKANKUNTI, Ph.D.

The objective of the study was to estimate the relative technical efficiency of public hospitals in PNG and estimate the magnitudes of output increases and/or input reductions that would have been required to make relatively inefficient hospitals more efficient using Data Envelopment Analysis for 20 hospitals in PNG using the data for 2017. The study is further extended using the Tobit regression analysis to investigate the institutional and contextual factors on hospital efficiencies.

The results of the output-oriented DEA BCC Model indicated that the average constant returns to scale technical efficiency score was 79%; the average variable returns to scale technical efficiency score was 92%; and the average scale efficiency score was 86%. The 7 inefficient hospitals need to increase the overall outpatient visits by 31%, and inpatient discharges by 27% to be efficient. Alternatively, inefficient hospitals could also have improved their relative efficiency by reducing their overall beds by 19%, doctors by 34%, nurses by 13%, and other staff by 31%. The pattern of scale efficiency showed that out of 7 inefficient hospitals, 2 hospitals operated under increasing returns to scale while 5 hospitals operating under decreasing return to scale.

For this study, the focus is on the technical and scale efficiency score, which could be used for hospital planning and management policies. The Tobit regression model result indicated that the ratio of bed to nurses (RoBTN) is significant and positively correlated with inefficiency scores. In other words, a unit increase in RoBTN will increase the inefficiency of hospitals by 19%. It is noted that additional nurses for the available beds to effectively minimize the inefficiency. Additionally, the ratio of bed to doctors (RoBTD) is significant and negatively correlated meaning available doctors need to be reduced to minimize the inefficiency. A better approach and policies are required for hospital management to allocate and shift doctors within the hospitals for better efficiency. Hospitals with more beds are significant and are negatively correlated with inefficiency scores. Additional beds are required to minimize the inefficiency for better and effective health services.

Public hospital improvement policies can have various links to resource allocation within and between hospitals, some reflected in demand for health personnel, and some in the types and skills available on the supply side. The study results illustrate part of the range of possibilities for selected components of the hospital management plan. Many effects, whether the direct effects that define the policy, indirect side effects, or conditionalities imposed directly or indirectly, will vary with the components and details of the plans. Therefore, there are no general statements about links to hospital inefficiency improvement based only on theoretical analyses of the technical and scale efficiency score. The interpretation of the findings for policy recommendations should be made with caution.

Field of Study:	Health Economics and Health Care Management	Student's Signature ....
Academic Year:	2020	Advisor's Signature ....

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James Noah

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List of Abbreviations

CHW:	Community Health Workers
CMC:	Church Medical Council
CRS:	Constant Return to Scale
CRSTE:	Constant Return to Scale Technical Efficiency
DEA:	Data Envelopment Analysis
DMUs:	Decision Making Units
DRS:	Decreasing Return to Scale
FIS:	Facility Inventory System
GDP:	Gross Domestic Products
HEO:	Health Extension Officer
IRS:	Increasing Return to Scale
LLGs:	Local Level Governments
MDGs:	Medium Development Goals
NDoH:	National Department of Health

NHIS:	National Health Information System
NHP:	National Health Plan
NHSS:	National Health Service Standards
OTE:	Overall Technical Efficiency
PHA:	Provincial Health Authority
PNG:	Papua New Guinea
PPF:	Production Possibility Frontier
PTE:	Pure Technical Efficiency
SFA:	Stochastic Frontier Analysis
VRS:	Variable Return to Scale
VRSTE:	Variable Return to Scale Technical Efficiency
WHO:	World Health Organisation

CHAPTER I: INTRODUCTION

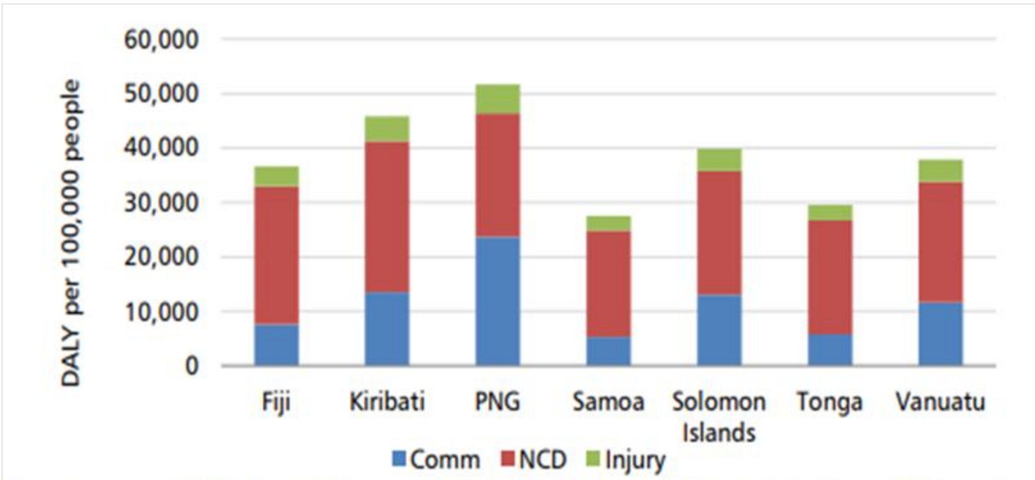
1.0 Background and Rationale

In any developing economy, health expenditure is the largest component of the government budget and Papua New Guinea (PNG) makes no exception. While comparing with other Pacific Island countries, the PNG health system is very complex. The cost of service delivery is very high due to rural terrain and no proper road links to the rural population where 80% of the population lives. Natural catastrophes are more common, which impede access to health services and present a challenge for the health personnel in rural settings.

Papua New Guinea has a parallel health system, with primary health care is managed by provinces. In contrast, secondary and tertiary health services are governed and coordinated through the National Department of Health (NDoH). Approximately 2,608 facilities in the country of which 20 hospitals, 11 district hospitals, 78 urban clinics, 190 health centers, 449 sub-health centers, and 1860 aid post/community health posts (NDoH-NHIS 2015).

PNG has the highest health problems in the Asia Pacific Regions in terms of the burden of diseases as shown in figure 1.1. Infectious diseases like malaria, tuberculosis, diarrhoeal diseases, and acute respiratory disease are significant causes of morbidity and mortality. Prevalence of non-communicable diseases (NCDs) are most common in many parts of the communities in the country. Rates of infant and child mortality and maternal mortality are high compared to other countries in the Asia Pacific Region. Roughly 41% of male and 49% of female deaths in Papua New Guinea are due to infectious disease. Almost 45% of male and 42% of female deaths arise from NCDs. Infectious diseases, maternal, neonatal, and nutritional conditions account for more than half of the deaths especially in parts of the country with low socio-economic status (Kitur, Adair, Riley, Lopez, 2019).

Figure 1. 1 Burden of disease in selected Pacific Island Countries in 2010



Comm= communicable disease, DALY = disability-adjusted life year, NCD = non-communicable disease, PNG = Papua New Guinea.
Source: Institute for Health Metrics and Evaluation. http://vizhub.healthdata.org/gbd-compare/

For effective coordination and management of the health system, PNG has implemented three reforms in the health sector. These include Direct Facility Funding (DFF), Free Primary Health Care and Subsidized Specialized Health Services (FPHC & SSHS), and Provincial Health Authority (PHA).

DFF was critical that funds reached the point of service delivery, which is at the health facility level. This reform has been trialed out with the support of the New Zealand Aid but has ended when the New Zealand government graduated its support to the health sector over the years. It was initiated to ensure public funding reaches the frontline health facilities and is readily available to finance the priority activities, especially at the lower-level facilities. Most facilities (both government and church-run facilities) rely on the collection of user fees to fund their operations. Thus, these reforms add value to the operations and delivery of rural health services in the country.

As part of the government's priority, PNG also introduced the FPHC and SSHS in 2012 and was implemented in 2014. The policy objective was to offset the user fees at the primary level of care and subsidized the specialized health services, especially at the secondary level of the facilities, to promote accessibility and equitability (National Department of Health, 2013).

PHA was another reform legislated and acted by parliament in 2007 and is currently being implemented. This legislation streamlines the provision of health services at the provincial level (level 1 to level 4 facilities) and hospital management services (level 5-7) under one management board. The creation of PHA has created opportunities to better deliver health services under a single health institution with management and control of all health resources and services in the provinces more effectively (World Bank 2014).

1.1 Problem Statements

Necessary resources for the hospitals must be proportionally resourced to ensure fully operational at all times. Like any other developing nation in the world, today PNG is faced with an increasing scarcity of resources for effective health care service delivery. The shortage of physicians and nurses is a critical constraint. The aggregate number of health workers in PNG is considerably lower than the World Health Organization (WHO) minimum threshold density of 2.28 per 1,000 population to achieve the health-related Medium Development Goals (MDGs) (World Bank 2011).

In addition, PNG health expenditure is estimated at 4.3% of gross domestic product (GDP). Within the health sector, hospitals consume the highest proportion of health resources at 31 percent of the health budget (National Department of Health 2012). However, there are few improvements in health indicators which implied that the available resources haven't been utilized efficiently. It has become the major constraint in pursuing the goal of improving the health status of the population (National Department of Health 2017).

Currently, there is a considerable **knowledge gap** in the measurement of health facility performances. Studies on hospital efficiency measurements in PNG are very limited. The current study draws to examine the overall technical efficiency of the twenty (20) public provincial hospitals in Papua New Guinea. The study will focus on out-patient visits and in-patient discharge as the key output indicators in terms of health service delivery from the hospitals. The *possible benefits* of the study might include an understanding of the performance of the hospitals. The utilization and applications of the findings or results may also be used as the blueprint for doing resource allocations, policy formulations, and make informed decisions in the resource distribution.

1.2 Research Questions

What are the determinants affecting the technical efficiency, pure and scale efficiency of the public hospitals in Papua New Guinea?

1.2.1 Objective of the Study

1.2.1.1 General Objectives:

To measure and investigate the technical efficiency, pure and scale efficiency of the public hospitals in Papua New Guinea

1.2.1.2 Specific Objectives:

- To measure the level of technical efficiency, pure and scale efficiency of the Individual Hospitals using the Data Envelopment Analysis (DEA).
- To estimate the magnitudes of output increases and/or input reductions that would have been required to make relatively inefficient hospitals more efficient and
- To compare the efficiency of the hospitals among the four Regions; Islands, Highlands, Southern, and Momase.
- To investigate the factors influencing hospital inefficiency using the Tobit regression model.

CHAPTER II: PAPUA NEW GUINEA HEALTH SYSTEM

2.0 Country Background

Papua New Guinea is located south of the equator and it's about 160 km towards the north of Australia. It is part of the arc mountains stretching from Asia, through Indonesia into the South Pacific, and consists of more than 600 islands. The Papua New Guinea population is estimated at 7.06 million, with a national growth rate of 2.83 percent between 2000 and 2011. Almost 80% of the people are living in rural areas while 20% of them are living in urban centers mainly cities and towns (National Department of Health 2012).

PNG is a lower-middle-income country with an economy being heavily dependent on the natural resources sector. It has complex geography – with large areas of the country accessible only by foot, air, or boat. The country is classified into four geographical regions; highlands, Islands, Momase, and the Southern region. Administratively, the country is made up of 22 provinces, 89 districts, and 318 rural local-level governments (LLGs), and 31 urban LLGs.

PNG demonstrates a high burden of communicable and the prevalence of NCDs. Life expectancy is shorter and infant mortality is higher than most neighboring Pacific Island countries. Both infant and under-5 mortality have not adequately achieved and meet its MDG 4 which calls for reductions by 2015 in under-5 mortality from 90 (in 2000) to 32 per 1000 live births, and in infant mortality from 64 (in 2000) to 24 per 1000 live births. Maternal mortality is a serious problem in PNG, 53% of births are attended by skilled health personnel. The leading health problems are communicable diseases, malaria, tuberculosis, diarrhea diseases, and acute respiratory disease as major causes of morbidity and mortality (WHO and the National Department of Health (PNG) 2012).

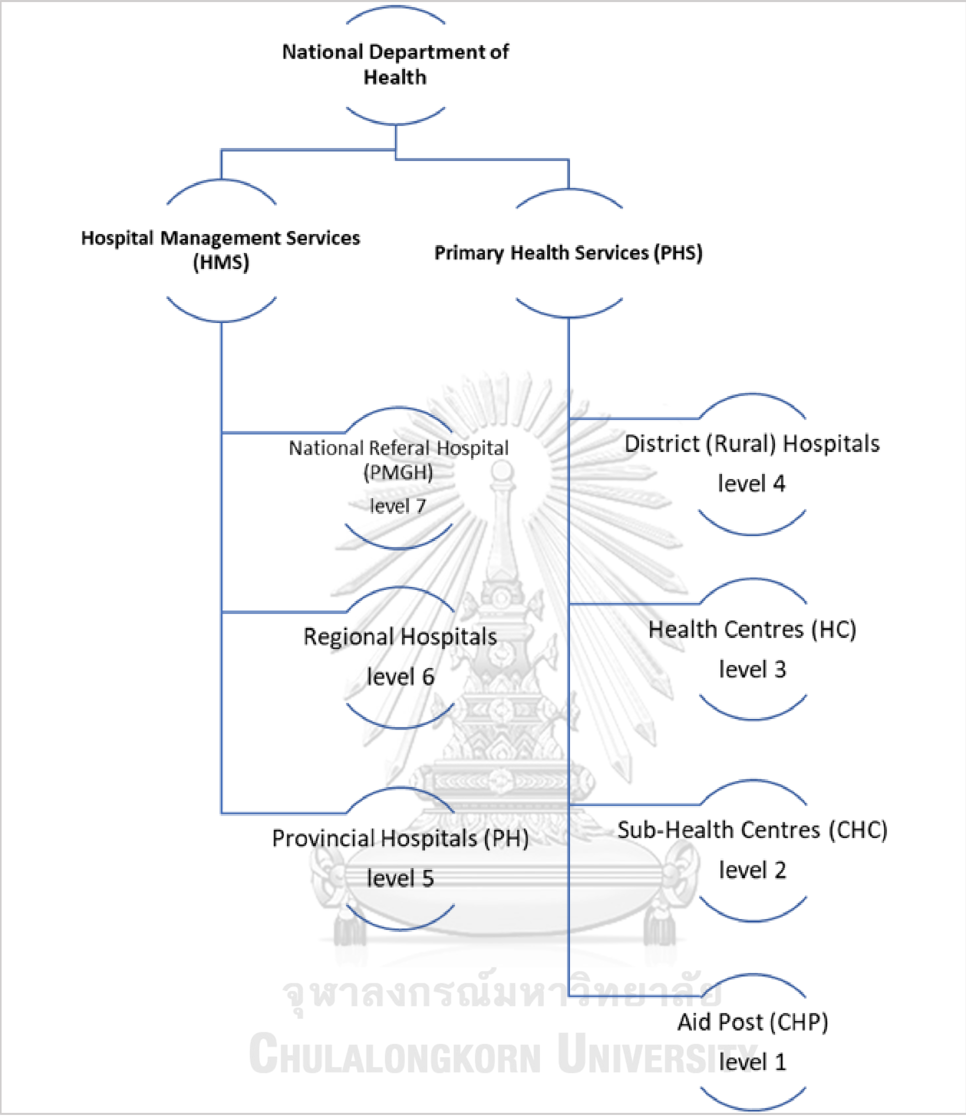
The Current Health Expenditure was around 4.3% of GDP as of 2014. This was still lower than the other neighboring pacific Island countries and South East Asia (National Department of

Health 2012). A diverse population and rugged terrain and mountainous geographical locations are a big challenge in providing effective health services especially in remote parts of the country.

2.1 Health Service Delivery Model

Figure 2.1 shows the hierarchical structure outlining the level of health facilities in PNG as stipulated by the National Health Service Standard (NHSS). The national health system is divided into 7 levels of health care delivery. Level 1 consists of the aid post or community health post (CHP) which is the first level of contact between communities and the formal health sector. Level 2 consists of sub-health centers, level 3 is the health center, and level 4 is the district hospital, which is the first referral hospital in the system. Level 5 consists of provincial hospitals with some specialized services, and level 6 consists of the regional hospitals. Level 7 is the national referral hospital, Port Moresby General Hospital (National Department of Health (PNG) 2011).

Figure 2. 1 The structure and the level of health facilities in PNG Health System



The descriptions of the health facility levels are given below (WHO and the National Department of Health (PNG) 2012);

1. *Aid Post/Community Health Post:* These facilities deliver basic health care including mother and child care, and community-based health promotion. Staffed by community health workers with two years of training. Aid posts are designed to cover a population group of about 1,000 people each are the first point of contact with the communities.

2. *Sub Health Centre:* These levels of facilities are delivering the same services as health centers.
3. *Health Centre:* Health centers and sub-centers provide services including management of chronic and acute conditions, basic surgical care, deliveries, and pediatric care, and function as intermediary referral points between district lower-level facilities and district hospitals. These facilities are established in geographical areas with 5 000 to 20 000 population.

4. *District Hospitals:* Provide full basic health services including medical, surgical, obstetric, pediatric, trauma, and 24-hour emergency care for both inpatients and outpatients. District hospitals cover a population of 40,000 to 300,000 depending on the availability and accessibility of other health facilities nearby.

5. *Provincial Hospital:* A hospital provides specialized clinical and diagnostic care; management of high-risk pregnancies and complications of pregnancy; technical and logistical backup for epidemiological surveillance.

6. *Regional Hospital:* A regional hospital provides specialized clinical and diagnostic care; management of high-risk pregnancies and complications of pregnancy; technical and logistical backup for epidemiological surveillance more similar to the provincial hospitals
7. *National Referral Hospital:* National Referral Hospital provides specialized clinical and diagnostic care; management of high-risk pregnancies and complications of pregnancy;

technical and logistical backup for epidemiological surveillance; and research and training. It is also the teaching hospital in PNG.

2.2 PNG Health System

The health care system in Papua New Guinea is highly decentralized based on the 1995 Organic Law on Provincial and Local Level Governments. The sub-national level of the system, which is comprised of 22 provinces and 89 districts, is responsible for the implementation of the National Health Plan (NHP) or the delivery of primary or rural health services. The central government is responsible for setting and formulating national policies, standards, legislation, and oversight on the implementation of this plan and policies.

Before 1994, the health system operated as two separate or parallel health systems. Public hospitals operated under the 1994 Public Hospital Act, and rural health services or public health programs operated under the 1997 National Health Administration Act. This led to the fragmentation of the health system which contributed to poor and uncoordinated service delivery across the country. However, in 2007, Parliament enacted the Provincial Health Authority (PHA) Act. The PHA Act integrates health administration, financing, and human resources management under a single health authority. This reform streamlines the management of rural health services and hospital management under one authority – the Provincial Health Authority. This reform has been piloted and almost completed in all the provinces.

Rural health services delivery is also supported by the government-subsidized health services provided by various Christian Missions. Other NGOs, mining industries, and private sectors also provide clinical health services, especially in rural settings. Development partners' support in terms of clinical, financial, and technical supports in the health sectors whether directly or indirectly are equally important for better health care (World Bank 2014).

2.3 PNG Health Care Providers Network

As alluded to in the previous sections, the service delivery in PNG is mainly provided by the government and church-run facilities. It was funded mainly by the government budget, out-of-pocket, and supports from development partners.

2.3.1 Private & Primary Health Services

The central government is responsible for the provincial hospitals including the four (4) regional and the national referral hospitals. The provincial government is responsible for the rural health services which include level 1 up to level 4 facilities (aid post, sub-health centers, health centers, and rural hospitals).

Among the government facilities, church health facilities are also an integral part of the national health system, particularly in the most hard-to-reach rural areas of the country where almost 80% of the population lives. They provide almost 50% of the primary health services to the rural population. Churches have had ongoing involvement in health service delivery since colonial times. The work of the church health service has been started by the missionary nurses who came into PNG soil in 1848 and eventually spread across the country establishing facilities and other basic services that people need in the 19th and 20th centuries (World Health Organisation 2019).

Church agencies manage their plans and staffing but are highly subsidized with the money in the form of grants. Over 80% of the service costs are financed by the government without any formal contractual arrangement. Church organizations also run 6 of the 9 nursing schools and 14 community health worker training schools, but again there is no formal contractual arrangement with the government and thus, have no clear links with overall national health workforce planning or requirements (WHO and the National Department of Health (PNG) 2012). Private sector organizations include for-profit enterprise-based services or employment-related health care programs, small for-profit private sector, women's and youth organizations, Non-Government Organizations (NGOs), and an undocumented number of unregulated traditional healers are also part of the basic health care providers. Many of these NGOs and faith-based organizations are funded by external financial supports from their originating organizations and other development partners.

2.3.2 Hospitals

PNG's Hospitals are managed, coordinated, and governed through the central government. Currently, there are a total of 20 public hospitals established as statutory authorities and are administered under the Public Hospitals Act (1994). These public hospitals include all the level five (5) provincial hospitals, level (6) regional hospitals, and Level (7) national referral hospitals. Table 2.1 shows four regions and has four provincial hospitals operate as regional hospitals; Mt Hagen Hospital for Highlands Region, Noga Base Hospital for Island Region, Angau Hospital for Momase Region, and Port Moresby General Hospital for Southern Region. Port Moresby General Hospital is also operated as the National Referral Hospital in the country. All these 20 hospitals are public and situated at the heart of the towns and cities. District hospitals including other lower-level facilities are away from town areas into the districts and local level government in the rural settings.

Table 2. 1 Characteristic of the Public Hospital in PNG

NO	REGION	PROVINCE	FACILITY TYPE	OWNERSHIP	LOCATIONS
1	HIGHLANDS	KUNDIAWA	KUNDIAWA HOSPITAL	PUBLIC	URBAN
		GOROKA	GOROKA BASE HOSPITA	PUBLIC	URBAN
		WABAG	WABAG HOPITAL	PUBLIC	URBAN
		MENDI	MENDI HOSPITAL	PUBLIC	URBAN
		MOUNT HAGEN	MOUNT HAGEN HOSPITAL (REGIONA	PUBLIC	URBAN
2	ISLANDS	KOKOPO	NONGA BASE HOSPITAL (REGIONAL)	PUBLIC	URBAN
		LORENGAU	LORENGAU HOSPITAL	PUBLIC	URBAN
		KAVIENG	KAVIENG HOSPITAL	PUBLIC	URBAN
		BUKA	BUKA HOSPITAL	PUBLIC	URBAN
		KIMBE	KIMBE HOSPITAL	PUBLIC	URBAN
3	MOMASE	WEWAK	BORAM HOSPITAL	PUBLIC	URBAN
		MADANG	MADANG HOSPITAL	PUBLIC	URBAN
		LAE	ANGAU BASE HOSPITAL (REGIONAL)	PUBLIC	URBAN
		VANIMO	VANIMO HOSPITAL	PUBLIC	URBAN
4	SOUTHERN	NCD	PORT MORESBY GENERAL HOSPITAL (REGIONAL/REFERAL)	PUBLIC	URBAN
		KEREMA	KEREMA HOSPITAL	PUBLIC	URBAN
		ALOTAU	ALOTAU HOSPITAL	PUBLIC	URBAN
		POPONDETTA	POPONDETTA HOSPITAL	PUBLIC	URBAN
		DARU	DARU HOSPITAL	PUBLIC	URBAN
		CENTRAL	LALOKI HOSPITAL	PUBLIC	URBAN

The following clinical services are generally provided by hospitals: internal medicine, surgery, pediatrics, obstetrics and gynecology, accident and emergency, and anesthetics. Health promotion, health improvement, and health protection on services are also be provided by hospitals (GoPNG (NDoH) 2010). Other functions as specified and described under the Public Hospitals Act (1994) and are;

- to provide curative care and support rural healthcare delivery
- to provide support to rural health services
- to conduct in-service training
- to develop agreements with the non-government sector to deliver health services

Most of these primary or ambulatory care is also provided by the hospitals. In other words, the level of hospital services is a mix of inpatient and outpatient cares at both primary and secondary levels. Therefore, all public hospitals provide general inpatients and outpatient care.

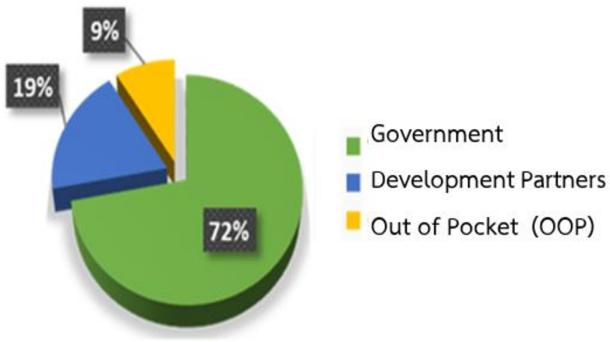
Specialized health services are mainly provided at the regional hospital at level (6) and the national referral hospitals at level (7) together with the general hospital services. For example, Angau Regional Hospital specialized in oncology but also provides general inpatient and outpatient care. However, the data for some of these specialist services are amalgamated and consolidated into outpatient and inpatient data. The data for specialized services are not reported separately. This is one part of the data limitation considered for the study.

The budgets and other resources are provided by the National Government through the normal budgetary process to the hospitals. The funding is managed by the hospital board including the human resources and their payroll system. Public hospital boards and provincial health boards report directly to the Minister for Health and HIV/AIDS. Reporting of performance indicators through the national information system (NHIS) is coordinated by the National Department of Health. This study sourced secondary data from this routine information domain (NHIS). The central government is responsible for all these hospitals (level 5-7) in terms of governance, coordination, and reporting (WHO and the National Department of Health (PNG) 2012).

2.4 Health Care Financing

Papua New Guinea's health system is provided and subsidized mainly by the consolidated tax revenues through the normal budgetary process every year. Almost 72% of the health funding comes from the state through the general taxations and substantial support from external donors. The donors and out-of-pocket (OOP) accounted for 19% and 9%, respectively as shown below in figure 2.2 (National Department of Health 2012).

Figure 2. 2 Current Health Expenditure by funding source



Source: PNG NHA (2012)

The central government allocates public funds for services delivery at every health facility in the country. Primary Health Service is funded through the health functional grants (HFG) directly to the provincial government. The HFG is a constitutional grant from the National government earmarked for primary health services which are managed by provinces for spending. In principle, all public health and primary health care services are free of charge. However, the facilities charged user fees at the point of service delivery. This user fee collection is important to fund the immediate funding needs to make the facilities functioning if funding (HFG) delays reaching the facilities for implementation on time through the government system.

Church Health facilities are highly subsidized with grants from the national government budget through the Christian medical council (CMC). CMC is a secretariat of the church agencies which liaise with the NDoH in terms of receiving and disbursements of the church grants to their respective church agencies for implementations. Churches provide almost 50% of the rural health services in rural PNG. The respective church agencies manage their plans and staffing but are highly subsidized with over 80% of the service costs financed by the government, without any formal contractual arrangement. In principle, churches are part of the local planning and decision-making process under the coordination of provincial and district authorities but in practice, participation is limited (WHO and the National Department of Health (PNG) 2012).

All the health service providers (hospitals, primary health service providers, churches, NGOs) are also supported by external funding agencies. Almost 20% is financed by development partners. The funding is either provided directly to the facilities or indirectly through the normal government system. Medical supplies and wages and salaries of the health workforce are the national government's functions. The salaries and wages are managed separately by the department of personnel management (DPM) whereas the medical supplies are procured and coordinated by the national government.

CHAPTER III: LITERATURE REVIEWS

The keywords used in the online database include the following; Data Envelopment Analysis, Technical Efficiency, Public Hospitals, and Tobit Regression. A total of eleven (11) journals, research papers, and articles were searched and reviewed. This chapter discusses the main concepts used in the literature which are related to the nature of this study conducted.

3.1 Data Envelopment Analysis (DEA)

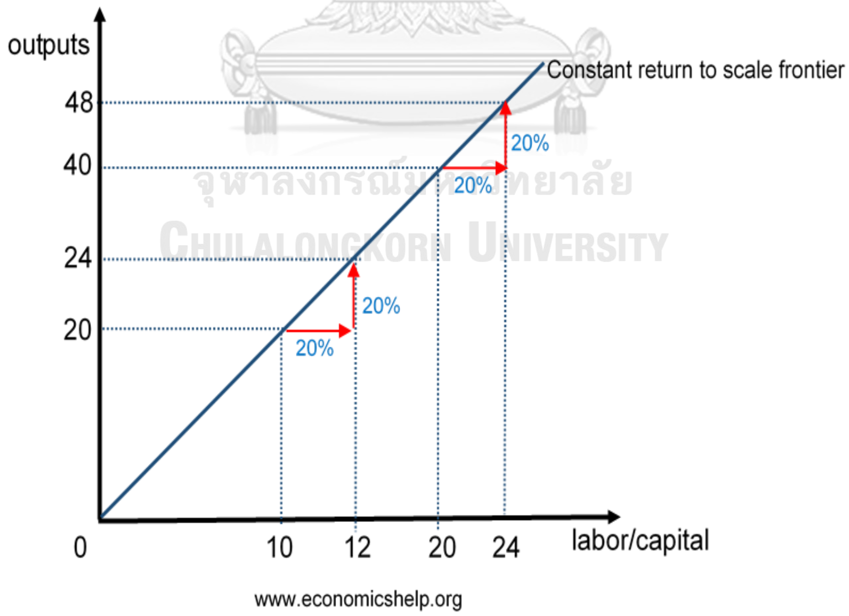
DEA is a non-parametric approach that relies on mathematical programming methods for estimating efficiency and capacity utilization, effectively identifying the production frontier. The development of the DEA concept has started in the late 1970s from the theoretical work of efficiency measurement by Koopmans (1951). Charnes, Cooper, and Rhodes (1978) have initially modified the efficiency concept based on Farell's (1957) framework and introduced the DEA model which was then extended by Banker, Charnes, and Cooper (1984). Since then, the development of the DEA concept has become more popular through the use and its applications in many areas of research in both the private and public sectors (Ruggiero 1996).

The common goal of the DEA model is to measure the performance of the firms or entities (called Decision-Making Units –DMUs), which convert multiple inputs into multiple outputs in the production process. Firm efficiency is defined as the ratio of the sum of its weighted outputs to the sum of its weighted inputs based on Farrel's (1957) radial efficiency measurements (Awara and Susan 2019). DMUs that are technically efficient have a score of 1 or 100%, whereas inefficient ones have efficiency scores of less than 1 (i.e., less than 100%) (Mujasi, Asbu et al. 2016). The concept of efficiency and the types of DEA models are discussed in the next part of this paper.

3.1.1 Charnes, Cooper and Rhodes (CCR) Model

The original DEA model was developed by Charnes, Cooper, and Rhodes (1978) and referred to as the CCR model, assuming a production technology with constant returns to scale (CRS). This model implies that any change in inputs should produce a proportional change in output. The technical efficiency scores for DMUs under the CCR model have the same values in input or output orientation. But these values will be different according to the model's orientation when the variable return to scale (VRS) is assumed which is discussed in the next section. Figure 3.1 shows the CRS frontier with the labor/capital as inputs and outputs. If a company (DMU) increases its inputs by 20%, its outputs will also increase by 20%. Similarly, if the same DMU decreases the input by 20%, again, its output will be decreased by 20%.

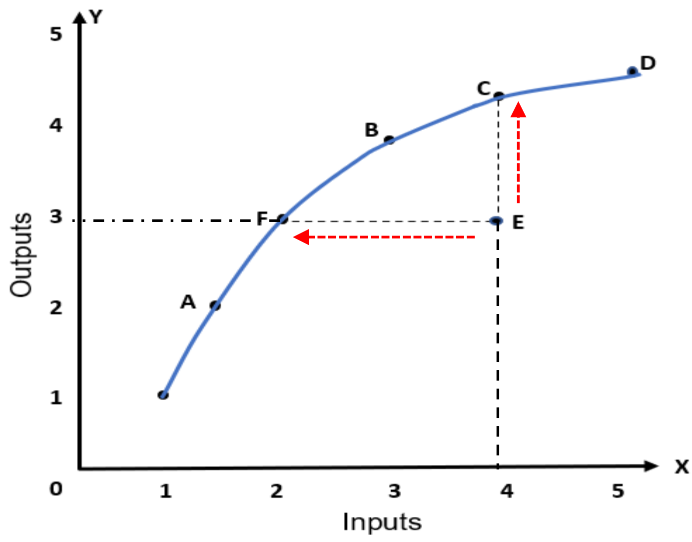
Figure 3. 1 Constant Return to Scale Frontier



3.1.2 Banker, Charnes, and Cooper (BCC) Model

The BCC model is one of the extensions of the CCR model that was modified and introduced by Banker, Charnes, and Cooper (1984) assuming that production is a variable return to scale (VRS) (Jarjue, Ghani et al. 2015). In contrast to the CRS model, the VRS model implies that the outputs do not change in proportion to the change in input. The concept of VRS can be either in the output-oriented or input-oriented model. In the input-oriented model, DEA minimizes input for a given level of output; in other words, it indicates how much a firm can decrease its input for a given level of output. However, in an output orientation, DEA maximizes output for a given level of input; in other words, it indicates how much a firm can increase its output for a given level of input. Figure 3.2 shows the VRS Frontier with the assumption that we have 1 input (nurse) and output (day treatment) as shown by the x and y-axis, respectively.

Figure 3. 2 Variable Return to Scale (VRS) Frontier



As shown in figure 3.2, we have possibility sets of A, B, C, and D. You can see that all other units are efficient except E, which is inefficient. Based on the input-oriented model, E would be projected to F to become efficient by reducing the input from E to F at the given output level of 3. On the other hand, in the output-oriented model, E can be projected to C by increasing output from E to C to become more efficient at the given input level of 4.

3.2 Efficiency

The term "efficiency" is widely used in economics and refers to the best uses of available economic resources in production. Efficiency was discussed and practically implemented in the work of (Farrell, 1957) for measuring efficiency based on the efficiency definition of (Koopmans, 1951) and (Debreu, 1951). The concept of efficiency means producing the maximum amount of output from a given amount of input or producing a given output with minimum quantities of inputs. Thus, when a firm (in our case, a hospital) is technically efficient, it operates on its production frontier.

For a hospital to be economically efficient, it needs to be technically efficient. The hospitals can accommodate and use the right mix of health inputs at the given set of prices to produce at the optimal output level. Therefore, economic efficiency is attained when obtaining maximum benefits from a given cost or minimizing the cost of obtaining a given benefit (Hollingsworth, Dawson et al. 1999). Economics efficiency can be *technical efficiency* (producing without waste) and *allocative efficiency* (allocate resources to the highest value use) as discussed below.

3.2.1 Technical efficiency

Technical efficiency means producing maximum output with given inputs; alternatively, using minimum inputs to produce a given output. Technical efficiency is measured by the relationship between the physical quantities of output and inputs (Azreena, Juni et al. 2018).

In terms of health production, technical efficiency is achieved when a hospital produces a given level of health service as outputs with the least health system inputs such as health workforce, pharmaceutical, and nonpharmaceutical supplies and capital (buildings, beds, equipment, vehicles, etc.). To be efficient health production level need to be located on an isoquant (or production possibility frontier (PPF)). It is inefficient when it deviates away from the PPF line (Mujasi, Asbu et al. 2016).

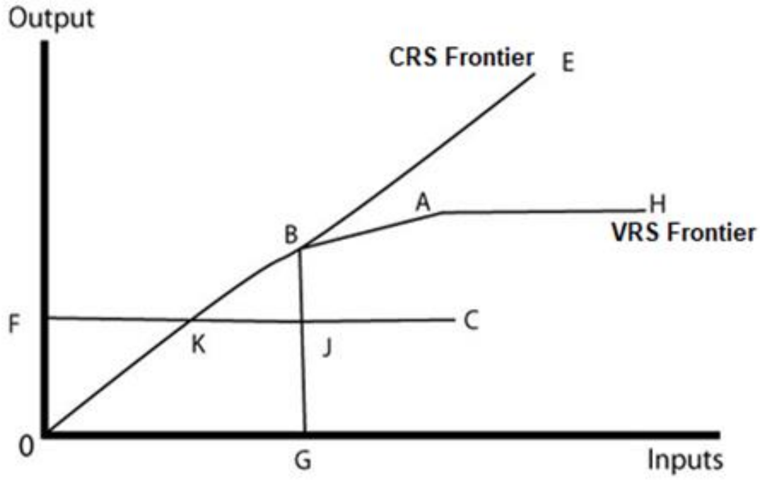
Under CRS assumptions, the measure of technical efficiency is known as *overall technical efficiency (OTE)*. The OTE measure helps to determine inefficiency attributable to input/output combination and scale sizes (Kumar and Gulati 2008). According to (Mujasi, Asbu et al. 2016), OTE measure has been decomposed into pure technical efficiency and scale efficiency (SE). Pure technical efficiency (PTE) denotes the measure of health decision-making unit technical efficiency without scale efficiency and purely reflects the managerial performance to organize the inputs in the health production process. Thus, the PTE measure has been used as an index to capture managerial performance. The ratio of OTE to PTE provides SE measure.

On the other hand, *scale efficiency (SE)* measures the extent to which a health decision-making unit deviates from the optimal scale. In other words, SE provides the ability of the management of the health unit to choose the optimum size of resources, i.e., to decide on the hospital's best optimal size that will attain the expected production level.

Return to scale is the extent to which hospital (health unit) output changes as a result of a change in the quantity of all hospital (health unit) inputs used in the production. In other words, it describes the rate of increase in the hospital outputs relative to the associated inputs used (Kirigia and Asbu 2013). Kumar & Gulat (2008) explained that the inappropriate size of hospitals (too large or too small) might sometimes be a cause of technical inefficiency. This is referred to as scale inefficiency and takes two forms: decreasing returns-to-scale (DRS) and increasing returns-to-scale (IRS). DRS is achieved when health output is increased by less than the proportional change in all health inputs. This implies that the hospital is too large to take full advantage of scale and has a supra-optimum scale size. In contrast, IRS is achieved when health output increases by more than the proportional change in all health inputs. This implies that the hospital is too small for its scale of operations and, thus, operates at a sub-optimum scale size. However, if a hospital's output changes proportionally with its corresponding health inputs, then it's called constant returns to scale (CRS). In this case, the hospital is said to be scale efficient.

According to the DEA, the firm's efficiency is calculated with a complex mathematical model. However, the following figure 3.3 shows how the efficiency measurements are calculated to broaden the understanding of the concept OTE, PTE, and SE.

Figure 3. 3 Pure Technical and Scale Efficiency



Source: (Paço and Pérez

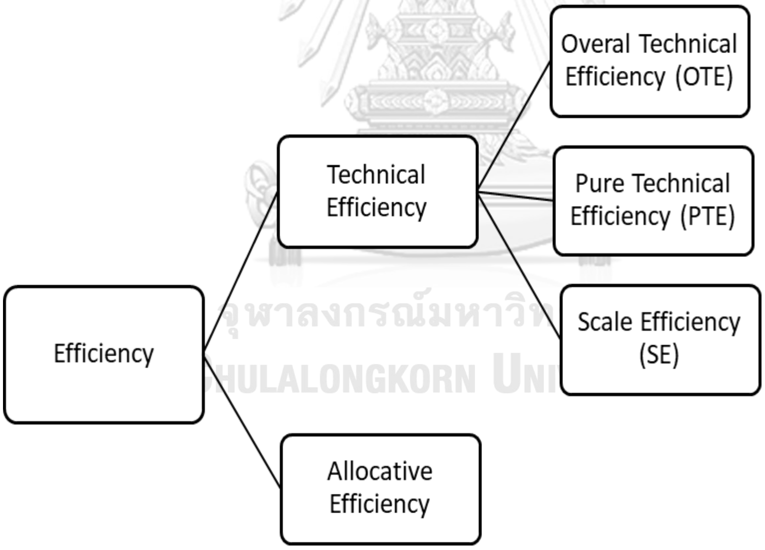
In figure 3.3, Y-axis represents output level and X represent combinations of two (2) input level. There are two (2) sets of frontiers. One is CRS described by line OE and another one is VRS represented by GBAH. The PTE of firm C is calculated based on VRS and that is (PTE = FJ/FC) and SE (SE = FJ/FK). The scale efficiency (SE) measures the productivity that can be improved by moving to the point of the technically optimal productive scale size. In other words, it measures the possible proportional reduction in the use of inputs if a firm operates with CRS rather than VRS. These concepts are also discussed with a case study in the next part of the paper.

3.2.2 Allocative efficiency

Allocative efficiency simply measures how an organization can choose optimal input combinations to produce maximum output combinations at the given price equals to marginal cost. In other words, allocative efficiency is the capacity of a firm to combine the outputs and inputs in adequate proportions, assuming set prices and with the available technology. The allocative efficiency can be measured when the prices of inputs and the output units are available (Hollingsworth, 2012). In terms of health service productions, allocative efficiency describes the use of health system inputs efficiently to minimize the cost of production at the given price level (Rithaa, Kosimbei et al. 2019).

So, in summary, the efficiency concept can be in two broad categories known as allocative efficiency and technical efficiency. Overall technical efficiency, pure technical efficiency, and scale efficiency are sub-components of technical efficiency which will be discussed in more detail in the next part of the discussions. The classification of the efficiency concept is presented in figure 3.4 below.

Figure 3. 4 Efficiency Classification



3.2.3 Productivity

Productivity is simply the ratio of output to input or it is output per unit of input. The concept of productivity is directly related to the measure of efficiency. However, they are not the same concept, even though they are occasionally treated as synonymous but their focus is different. They can be used together because they relate to each other especially when the interest of the research is centered on comparing the performance of the firms. For example, a firm's performance improves as it becomes more efficient and productive. In other words, change in productivity is due to changes in efficiency which relate to the efficient use of resources (González and Trujillo 2009).

Efficiency is about lowering the cost of the status quo of the resources used in the productions. Productivity is all about doing new things or improving the existing things that are done to create value and results. Productive organizations focus on improving their performance by changing the people worked to be more effective to achieve greater results. Productivity can be achieved through two things; introducing technical progress, for example, new MRI machines can increase productivity. Secondly, training of hospital staff to manage these machines, upgrade and upskills the capacity of the existing human resources to do the work more effectively.

Many researchers argued that productivity growth in health care has come in the form of improved quality rather than a lower cost. Furthermore, they argue that many of the innovations that have reduced costs and increased productivity such as moving from inpatient to outpatient care are not captured in the standard measures. Others, however, believe that even when properly measured productivity growth in the health sector is low because it is a service sector that has limited scope for efficiency improvements (Sheiner and Malinovskaya 2016).

3.3 Concept of Hospital Efficiency

In the context of the production of health services, technical efficiency is defined when hospital produces the maximum output (inpatient discharge, outpatient visits, etc.) from a given amount of health inputs (health workforce, hospital beds, physicians, etc.) or producing a given output with minimum input. That means the hospital need to make resource allocation decisions to achieve the maximum output in the form of hospital service (Azreena, Juni et al. 2018).

However, (Jacobs 2000) argued that health care institutions such as hospitals are not expected to be efficient because it doesn't conform to the principle of the neoclassical theory which states that firms operate to maximize profit. Nonetheless, hospitals are the largest organizations in the health care system and more resources are injected towards funding the hospitals. The allocations and utilization of the resources at the hospital are very crucial and important, which leads to a greater and growing interest in examining efficiency in the hospitals.

The author (2000) also elaborated that hospital efficiency is measured using financial resources with other indicators such as the number of patients treated, the average time it takes to admit a patient, or the number of surgical procedures, treatments, and diagnostic tests performed are also used for the efficiency measurements. The financial resource is one component of resources that stimulate and lubricate the functions of the hospitals. It funds both capital and operational expenses including other medical consumables and drugs.

A hospital may be too large for the volume of activities undertakes; and therefore, may experience diseconomies of scale. On the other hand, a hospital may be too small for its level of operation, and thus experience economies of scale. Efficiency scores of the hospitals are limited and lie between the lower and upper limits of 0 and 1. The hospital is technically efficient if the technical efficiency score is 100% or less if it's inefficient (less than 100%).

Furthermore, (Mujasi, Asbu et al. 2016) explained that efficiency scores across the countries are not only measured by the health resources but also some other contextual and environmental factors such as population catchments, size of the hospitals, etc. Many studies (Jacobs 2000, Mujasi, Asbu et al. 2016, Ali, Debela et al. 2017, Makheti 2017) have used statistical methods (Tobit regressions models) to investigate these contextual and environmental factors that have implications on the inefficiencies of the hospitals.

3.4 Methods of Measuring Hospital Efficiency

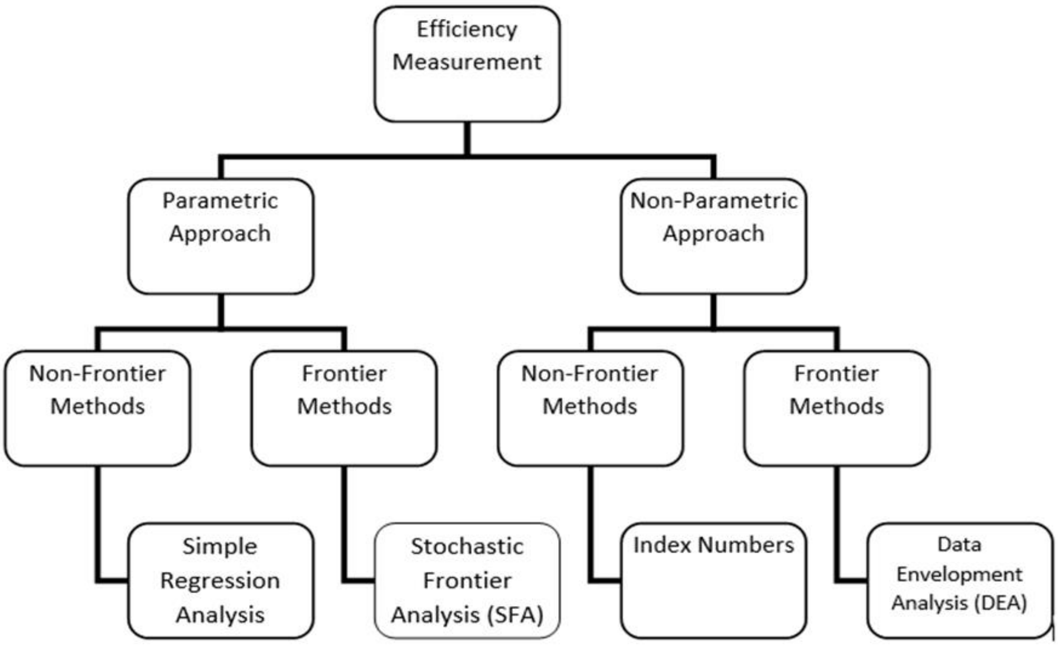
There are two main approaches to estimate the relative efficiency across firms: the parametric approach (or, more strictly, the statistical approach) and the non-parametric approach. Parametric and nonparametric methods of efficiency analysis have become dominant in the field of efficiency analysis. These two approaches have been employed as a measure of the economic efficiency of various sectors including health care units such as hospitals (Asmare and Begashaw 2018).

The parametric approach relies on econometric techniques and includes simple regression analysis and stochastic frontier analysis (SFA). On the other hand, the non-parametric approach uses mathematical programming techniques with DEA as the main non-parametric method. The main difference between these two approaches is that the parametric approach has a specific functional form for the production or cost function while the non-parametric one does not have any functional form.

The majority of efficiency studies have been motivated by the desire to estimate or measure economic efficiency based on either parametric or non-parametric frontier methods.

However, in the literature, the most commonly used method is the nonparametric approach specifically DEA in measuring the efficiency and productivity of health facilities. A possible taxonomy of efficiency techniques is illustrated in Figure 3.5.

Figure 3. 5 Taxonomy of the efficient measurement



Source: Sarafidis (2002)

3.4.1 Parametric Approach

The parametric approach relies on econometric techniques which include simple regression analysis and SFA. Whilst simple regression analysis typically seeks to estimate a production or cost function, SFA is an extension of that methodology to estimate the “frontier” of a set of functions with different underlying levels of efficiency. It is based on the applications of linear programming to construct a smooth parametric frontier with inappropriate structures of technology. The applications of parametric programming in health care are very few and limited to the use of stochastic frontier analysis (Hollingsworth, Dawson et al. 1999).

Under parametric approaches, the efficiency frontier is constructed based on econometric techniques to estimate either a deterministic or a stochastic frontier function. That means the production function is defined by the set of explanatory variables (labor, capital with other possibilities of technical changes) and the composite error terms, which include the standard error term and the inefficiency term. The stochastic frontier approach treats deviations from production function as comprising both random error and inefficiency terms.

3.4.1.1 Regression Analysis

Regression analysis involves the exploration of a relationship between a dependent variable (output) and certain independent variables (inputs). This relationship is usually represented by a fixed structural form (function), whose estimation in our context aims at identifying the efficiency. A simple regression model would be formulated to try to identify the relationship that best fits the observed data. This involves the use of ordinary least square (OLS) methods for estimating the statistical relationships between variables to identify the relative efficiency within a sample. OLS is used to fit the "best" line to the sample and involves minimizing the sum of the squared (vertical) deviations of actual observations from the fitted line (Sarafidis 2002).

In the health care sector, this approach could be used to provide information about the technical efficiency of a DMU, such as a hospital. For example, the production function of a hospital could represent the services provided by the hospital as the overall expected outpatient discharge while hospital staff, beds, and other technological equipment could be the inputs utilized. This relationship could be explained using a parametric econometric method, such as multiple linear regression analysis if many inputs (independent variables) are used.

A simple linear regression model with one independent and the dependent variable would be written as follows:

$$Y=\alpha+\beta X+\varepsilon$$

Where;

Y - is the dependent variable of interest (output);

α - is the intercept or constant of the equation;

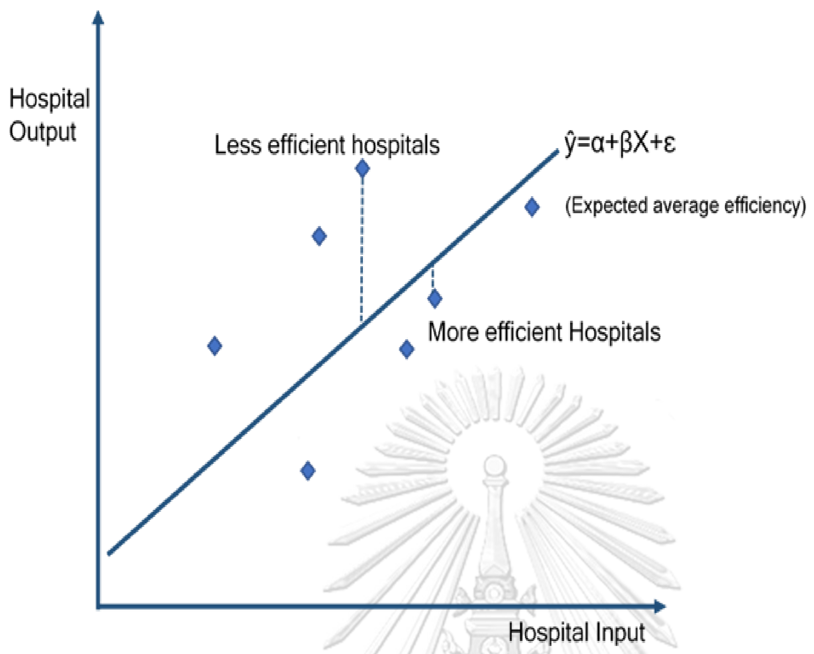
β - is the slope coefficient often referred to simply as "beta";

X - is the independent variable of interest (inputs); and

ε - is the residual, disturbance, or error term of the equation.

Figure 3.6 shows the simple 'one-input and one output linear regression case. The graph shows the "line of best fit" through a set of data points representing hospitals and is modeled from a population.

Figure 3. 6 Simple Linear Regression Analysis



The estimated dependent variable ("output") essentially provides the expected average quantity of output for each quantity of input used by the hospitals and this is represented by the fitted line of the estimated equation. In this case, the output production function of the hospital is perceived as the indicator of average technical efficiency for every input utilized (average efficiency rate). From figure 3.6, it is observed that not all the hospitals fall exactly on the fitted regression line. Some of the points are above while others are below the fitted line. The distance between the actual point of hospitals and the fitted line is the error or residuals.

Therefore, any divergence from the fitted line will correspond to a source of inefficiency. In other words, the smaller the residual or random errors, the better the regression line and therefore better the hospital's performance (Skrepnek, 2005).

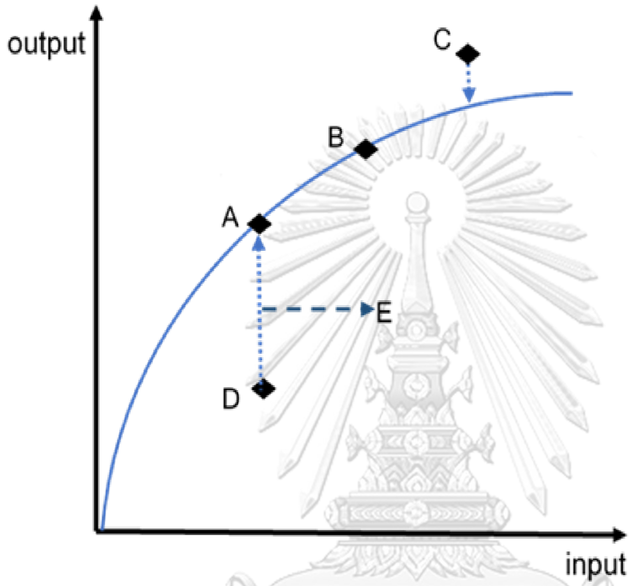
3.4.1.2 Stochastic Frontier Analysis (SFA)

SFA is another economic modeling based on the Parametric approach introduced by (Aigner, Lovell et al. 1977). The main idea of this approach is essential to expand the component elements included in the random error of the production function with the inclusion of the technical inefficiency. In other words, SFA presents a production function of the standard regression model but with a composite error term equal to the sum of inefficiency and the random error term. Any deviation from the frontier is also due to the presence of the technical inefficiency component. Essentially the SFA computes the technical inefficiency component to investigate and analyze the factors that have an impact on the level of output production. It will identify possible factors that may cause the DMUs or hospitals to be technically inefficient.

The random error accounts for statistical noise with zero mean and unknown variance while inefficiency represents a non-negative random variable associated with the technical inefficiency of a DMU or hospital. Essentially it requires separate assumptions to distribute the “inefficiency” and “error” components, potentially leading to more accurate measures of relative efficiency. The main advantage of this method is its capacity to treat separately the component of technical inefficiency and any random shocks or measurement errors present in the production. The three most common production functions used in the SFA analysis are Cobb-Douglas form, translog form, and multi-output distance form (Hamidi 2016).

Figure 3.7 illustrates the stochastic production frontier case using a simple production function. The graph shows point A and B are efficient meaning on the frontier. Point C represents technically efficient DMU with no inefficiency but rather positive external shocks contribute to higher output. On the other hand, point D represents an inefficient case. The distance AD is representing the deviations from the production function frontier as comprising both random error (noise) and the inefficiency error term. So now the line AD can be separated into line AE and DE corresponding to a component of random error and inefficiency respectively.

Figure 3. 7 Stochastic Production Frontier



73.4.2 Non-parametric approach

Unlike the parametric approach involving the stochastic frontier production function, the nonparametric method involves the data envelopment analysis. The non-parametric method uses linear programming to measure the relative efficiency of several decision-making units through the identification of the optimal mix of inputs and outputs which are grouped based on their actual performance. It is also used to measure the efficiency of a decision-making unit with multiple inputs and outputs.

The non-parametric approaches use mathematical programming techniques, and the primary non-parametric frontier analysis technique is DEA. DEA can also be seen as an extension of the simple technique of *index numbers* (Sarafidis 2002).

3.4.2.1 Data Envelopment Analysis (DEA)

As discussed in the earlier sections, the DEA is a non-parametric and relatively new “data-oriented” approach for evaluating the performance of a set of hospitals that convert multiple inputs into multiple outputs. DEA was initially developed by Charnes et al, (1978) as a measure of efficiency for private entities participating in public programs in the United States. Since then, the application of DEA has been extended in recent years in terms of evaluating the performances of the DMUs such as Hospitals, schools, etc. in all sectors. Many scholars and researchers have recognized DEA as an important tool for modeling operational processes for performance evaluations of hospitals.

DEA is based on the principle that the performance of each DMU must be compared relative to the best practiced DMU which acts as benchmarks. The ‘best-practice virtual frontier is essentially the combination of all efficient points of operation on the frontier. In this method, any deviation from the ‘best-practice frontier must be an indication of technical inefficiency. The current research will use the DEA method for measuring the efficiency of public hospitals in PNG and is discussed in more detail in the next chapters.

Some of the strengths and weaknesses of the DEA are stated below.

Strengths

Some of the advantages of the DEA methods include;

- no need to explicitly specify a mathematical form for the production function.
- proven to be useful in uncovering relationships that remain hidden for other methodologies.
- capable of handling multiple inputs and outputs.
- capable of being used with any input-output measurement

Weakness

- A major drawback of DEA is that it attributes all deviations from the frontier to inefficiency as;
- results are sensitive to the selection of inputs and outputs
- you cannot test for the best specification.
- the number of efficient firms on the frontier tends to increase with the number of inputs and output variables.

3.5 Previous studies on Hospital Efficiency Measurement

In the past three decades, health care efficiency has emerged as an issue of greatest interest to many governments and private sectors. This rise in interest is geared towards meeting the desired expectations of citizens by satisfying their health care needs.

DEA became more popular and used intensively by researchers all over the world for the past three decades. It has been widely employed in research in different health care delivery systems, such as general hospitals, acute hospitals, nursing homes, primary health systems, health centers, and profit and non-profit organizations (Azreena, Juni et al. 2018).

However, there is a significant knowledge gap in the use of DEA to measure and estimate the efficiency of the facilities in PNG. The studies on the efficiency of the facilities are very limited or non except by (Demir, Pulford et al. 2017) which investigated the utilization of health resources at the upper primary and secondary level facilities using ratio analysis methods such as bed occupancy ratios, input-output ratio, and cost output ratios. The study identified that upper secondary level facilities had allocated adequate resources than the upper primary facilities. It was recommended that necessary resources requirements at each of the facility levels must be provided to ensure the facilities are more efficient and fully functional at all times. More training institutions and facilities must be upgraded to meet the upper primary facilities' needs in terms of health personnel.

Many empirical studies in other countries aimed at measuring the efficiency of health care delivery units using Data Envelopment Analysis. Most of these studies in the literature are found in the African continent which focused on efficiency measurements of health institutions such as hospitals, district hospitals, and health centers. These include Ethiopia (Ali, Debela et al. 2017), Gambia (Jarjue, Ghani et al. 2015), Kenya (Kirigia, Emrouznejad et al. 2002), Namibia (Zere, Mbeeli et al. 2006), Ghana (Osei, d'Almeida et al. 2005, Akazili, Adjuik et al. 2008), Nigeria (Awara and Susan 2019) and Eritrea (Kirigia and Asbu 2013). Among them, few Asian countries including Bangladesh (Ahmed, Hasan et al. 2019) and Palestinian (Sultan and Crispim 2018).

The potential measurements of hospital inputs commonly used in the studies include the number of staff (both clinical and non-clinical) as a proxy to the labor input and the number of beds as a proxy to the capital input. Other additional inputs such as the cost of drug supplies, foods, and health expenditures in their analysis are also used by (Osei, d'Almeida et al. 2005, Akazili, Adjuik et al. 2008) and (Ali, Debela et al. 2017) in their studies.

On the other hand, outpatient visits and inpatient days or discharge were commonly used as the output variables with the inclusion of few individual programs such as immunizations, emergency care, antenatal care, deliveries, children immunized, family planning visits. In PNG, output data is reported as aggregated inpatient discharge and outpatient visits.

In **Namibia**, Zere et al. (2006) used the CCR model for the study. The study estimated that average technical efficiency scores ranged from 62.7% to 74.3%. Less than 50% of the hospital were efficient. The rest of them were inefficient due to the presence of pure and scale efficiency. However, the use of the government's recurrent expenditure for wages and salaries to the input combination was very challenging. The expenditure didn't give a clear picture of the types of staff in the facilities to disaggregate the salary component. A hospital with highly trained health personnel will bill a higher salary level even if the number of staff is small. This was not disaggregated due to a weak information system. That means findings under this scenario had not provided a clear policy guideline relevant for staffing in the hospitals even though the results revealed it required input reduction to be efficient.

Another study in **Ghana** by (Akazili, Adjuik et al. 2008) used an input-oriented BCC model identified that the degree of 89 randomly selected facilities performances was not efficient. The results have broadly indicated that the main issue of endemic inefficiency in the health care delivery system of public health centers was because of the underutilization of the input resources. The study suggested that significant amounts of resources could have been saved if measures were put in place to curb and avoid such waste.

The study by (Jarjue, Ghani et al. 2015) in **Gambia** used an output-oriented BCC model. There was a disparity in the number of staff as it was evident from the analysis that the total number of staff per health center ranged from 7 to 134. This disparity was due to the size, geographical location, and catchment area of the health center. The mean output for both inpatient and outpatient variables in the two years was 547.84 and 26,596 respectively.

According to the results, there was widespread inefficiency in the Gambian secondary health care service delivery as the mean efficiency score is 0.65 (65%) which is less than 1 (100%) and a standard deviation of (26%). Generally, Gambian Secondary health services had done very poorly except only 37% had an efficiency score above 0.80, which means that health centers were not efficient. They must obtain a score of 1 (100%) to be fully efficient.

Among the literature reviewed, (Kirigia and Asbu 2013, Mujasi, Asbu et al. 2016, Ali, Debela et al. 2017, Sultan and Crispim 2018, Ahmed, Hasan et al. 2019, Awara and Susan 2019) had extended their investigations using a statistical model to identify other contextual and institutional factors such as population size, hospital size, locations, the average length of stay, bed occupancy rate, etc. that affected the efficiency of the hospitals. The efficiency scores from the DEA analysis were regressed against the environmental and contextual factors to investigate the possible impacts on the inefficiency of the hospitals.

Ahmed et al. (2019) used an input-oriented DEA BCC model to estimate the efficiency of 62 district hospitals in **Bangladesh**. The DEA result revealed the general performance of the hospital was high because of the high utilization of hospitals despite some inefficiencies that existed with the individual comparisons of their efficiency scores. However, the Tobit results identified that hospitals with a target population of over 2.5 million had higher technical efficiency compared to hospitals with a target population of less than 1 million. Besides, hospitals situated at locations with a higher poverty headcount (15-30%) had higher efficiency than with less (<15%) poverty headcount. Moreover, the technical efficiency score of hospitals also increased with the increment of bed occupancy ratio and the ratio of beds to physicians and nurses.

A similar study by Sultan & Crispim (2018) using an input-oriented BCC model to estimate and investigate the efficiency of the 11 **Palestinian** Hospitals. The DEA method findings showed that potential savings of 15% of resource consumption were made without reducing the volume of current health services provided. However, the Tobit model revealed that bed occupancy rate (BOR); the outpatient-inpatient ratio (OPIPR); hospital's size (SIZE); and the availability of primary healthcare centers within the hospital's catchment area (PRC) had influences on the hospital efficiencies. Among these factors, OPIPR has a significant impact on the performance of the hospitals. Every 1 unit increase in OPIPR resulted in a reduction of inefficiency by 19%. Palestinians have limited studies in hospital performance, the results may become the blueprint for policy and planning process in the health sector.

Another study by Ali et al. (2017) used the DEA and DEA-based Malmquist productivity index used to estimate relative technical efficiency, scale efficiency, and total factor productivity index of hospitals in **Ethiopia** using six-year-round panel data. The study identified that efficiency across the facilities varies over time. Results from the Tobit model indicated that among other contractual and environmental factors, teaching hospitals were less efficient than other hospitals. This was because they treat severe cases that require a longer length of stay and thus require more resources which adversely affected the aggregate output level. The hospital that provides both health services and training is less efficient than other hospitals. Teaching alongside the provision of the health services may complicate and lose focus on the activities as they care for both the academics and health services provision.

Kirigia & Asbu (2013) on the other hand used an output-oriented BCC model to estimate the performance of the 20 public hospitals in **Eritrea** (Eastern Africa). The result identified that 42% of the hospitals were inefficient. The inefficient hospitals could have become more efficient by increasing output in terms of inpatient discharge and outpatient visits by 5.1% and 3.42% respectively. On the other hand, the hospitals could also save the access input resources and redistributed them to the lower-level facilities in need.

On the second-stage analysis, the ratio of outpatient visits to inpatient days (OPDIPD) and the average length of inpatient stay (ALOS) are significantly correlated to hospital inefficiencies. The 1-unit increase in the OPDIPD could reduce the inefficiency of the hospitals by 1.33. On the other hand, an increase in ALOS could increase the inefficiencies as it was positively correlated with the inefficiency scores. Essentially it required policy interventions to utilize the access resources and reduce the ALS would reduce the inefficiencies and improve the performances.

Mujasi et al. (2016) also used an output-oriented BCC model to measure efficiencies of the 18 hospitals in **Uganda.** This study was similar to that of (Kirigia and Asbu 2013) meaning that generally, the hospitals have performed well. The majority of the hospitals have utilized the resources well despite the few inefficiencies. The average pure and scale efficiencies were almost 90%. However, those few inefficient hospitals could have become more efficient by increasing the outpatient department visits and inpatient days by 45,943 and inpatient days by 31,425 respectively. Alternatively, it would also become efficient by redistributing their extra input resources to the other level of facilities.

Again, in the Tobit regression model, it indicated that OPDIPD and BOR were negatively correlated. OPDIPD and BOR are negatively correlated meaning will reduce the inefficiency of the hospital when they increase by 1 unit each. It further identified that the availability of more primary care facilities within the hospital's catchment area also increases the inefficiency level due to more patients are served at the lower level facilities at the same catchments area. The government needs to apply appropriate interventions to support inefficient hospitals to improve their efficiencies. One could be to have policies and strategies to increase demand for health services to utilize the hospitals rather than input reductions.

Similar recommendations had been made to a study done by Kirigia et al. (2002) in **Kenya**. DEA has demonstrated that 26% of hospitals were inefficient, and they need to either reduce their inputs or increase their outputs to become efficient. Again, access to input resources could have been redistributed to other facilities in need.

Finally, Awara & Susan (2019) estimated the performance of the hospitals in **Nigeria**. The study compared hospitals based on the ownership and size of the hospitals. The results identified that private hospitals were more scale inefficient than public hospitals while medium-sized hospitals were more scale inefficient than small size hospitals. The average level of technical inefficiency was higher in private hospitals (10.6%) than in public hospitals (8.7%) for the two periods of the study. Based on the size, the level of inefficiency was higher for medium-sized hospitals (10.6%) than for small-sized hospitals (9.1%).

The determinants of hospital efficiency were the number of patients seen (NPS) and the number of beds which had a positive and significant impact on the efficiency of hospitals. The implication is that the larger the hospital, the more efficient it will be. However, medium-sized hospitals were seen to be more inefficient than small-sized hospitals. The study recommends that measures to boost support of hospitals such as reducing user fees and the provision of health safety schemes could lead to an expansion in size with beneficial effects on the efficiency of such hospitals.

The summary of the literature review is provided in ***Appendix A*** for further information.

CHAPTER IV: METHODOLOGY

4.1 Study Design

This research will provide an overview of the public hospitals in PNG on their performances in terms of the technical efficiencies based on data availability. The data has been collected from the PNG National Health Information System (NHIS) domain. The data from 20 provincial hospitals for 2017 were used in this study.

The study was divided into two (2) parts;

a) The first part of the study design measured the efficiency of the hospitals using the DEA model. The DEA VRS output-oriented model was applied to measure the efficiencies of the hospital.

b) Secondly, after getting the results from the DEA of the efficiency scores, the Tobit regression model was used to define the determinant (contextual factors) that have a significant impact on hospital efficiency. The results would explain the variation in efficiency levels across the hospitals.

4.2 Type and Source of the Study

The study used the secondary data from the National Health Information System (NHIS) for output variable data and the Facility Inventory System (FIS) for the input variable data for the 20 provincial hospitals. Data was collected for the year, 2017 and thus the observation is 20.

The NHIS and Facility level information are routine activities for the provincial health services and hospitals to report to the National Department of Health on an annual basis on hard copies. The department then enters them into the NHIS and Facility Inventory System. The accuracy of the data depends on the timely and how effective data are sent from the provinces and actual entry to the system at the national level.

4.3 Conceptual Framework

Hospitals use multiple health inputs to produce various health service outputs through a production process. The inputs can be categorized as capital (number of beds, equipment, etc.) and health personals (medical doctors, nurses, etc.) to produce the outputs (outpatient visits and inpatient days/discharges) in the production.

The health production process does not occur in a vacuum; it can be influenced by environmental and institutional factors (both internal and external) (Mujasi, Asbu et al. 2016). Therefore, it is important to have further detailed analysis to examine the efficiencies of the hospitals with those institutional and environmental factors. Hence, the current study identified the hospital efficiency scores using the output-oriented DEA method followed by Tobit regression models.

At the first stage of the analysis, an output-oriented BCC model was applied to estimate the technical efficiency scores for each of the hospitals. Output oriented model was more appropriate because the health system in PNG is entirely funded by the government through the government budgetary process. According to the literature, (Kirigia and Asbu 2013, Mujasi, Asbu et al. 2016) when health system inputs are fixed, the output-oriented DEA model is more preferable. In this case, the hospital managers don't control the input allocations. They managed what is allocated and appropriated instead. Since all health resources are provided by the central government in fixed quantity every year, output orientation is more applicable.

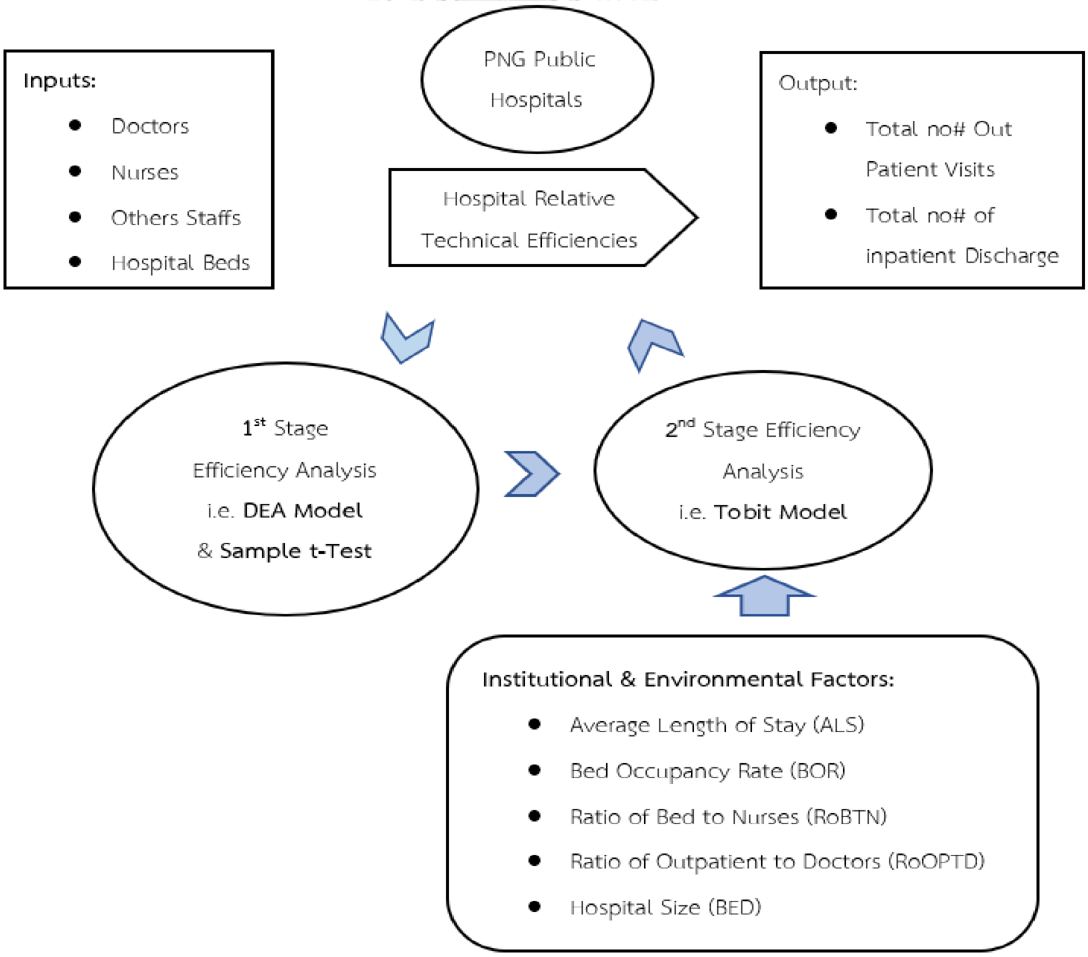
Furthermore, within the first stage of the analysis, a sample t-Test was conducted to test whether the PNG hospitals have technical inefficiencies. This provided the overall picture of the presence of inefficiency in PNG hospitals.

In the *second stage,* the econometric analysis (Tobit regression) was applied. This could be in line with the studies made by (Mujasi, Asbu et al. 2016, Ali, Debela et al. 2017, Sultan and Crispim 2018, Ahmed, Hasan et al. 2019) to analyze and regress the efficiency scores against the institutional and environmental factors to estimate their impacts on efficiency. The literature indicated that some of the factors have a significant impact on hospital efficiency while others do not.

Hence, in the current study, relative efficiency scores from the results of the DEA in the first stage of the analysis were further investigated using the Tobit regression model. That means efficiency scores of the hospital were treated as dependent variables regressed against the contextual factors to estimate their impacts on the efficiencies of the hospitals. These institutional and contextual factors were discussed in detail in the next part of the discussions.

The conceptual framework in figure 4.1 illustrates the first and the second stage of the analysis.

Figure 4. 1 Conceptual Framework Diagram



4.4 Rational of Selected Variables in the Study

To estimate and evaluate hospital efficiencies, it is important to know the resource requirements and the number of outputs it produces. There are multiple inputs that hospitals require to produce multiple outputs. In DEA, the input variables can be the health personnel, beds, equipment, etc. to produce inpatient discharge or inpatient days and outpatient visits, etc. as output. It is important to identify and know the unit of measurements of the inputs and outputs in the analysis.

In most cases, many researchers select variables based on the literature reviews conducted. The selections of inputs and outputs are driven and guided by past studies of hospitals that employ similar inputs and outputs for similar problem sets. The availability of relevant data in the ministry of health or an annual report can save costs or other resources required for primary data collections (Mujasi, Asbu et al. 2016). Normally it's costly to collect primary data.

4.4.1 Input Variables

From the reviews conducted (Karagiannis 2012, Makheti 2017, Ahmed, Hasan et al. 2019, Awara and Susan 2019), many potential measurements of hospital inputs are frequently used in the research studies. The selections of the inputs and outputs are based on the resources used and produced in the production process in the health facilities such as hospitals.

Essential hospital resources used for health service productions include the number of beds, machines, infrastructure buildings, equipment, health personnel (both clinical and non-clinical, etc. However, the bed is the proxy commonly used in the studies as the capital because it is important and has a significant relationship with its corresponding output like inpatient days or discharges. Doctors and nurses are used as the proxy to the labor including other medical and support staff as inputs.

The following inputs are selected for this study to identify the hospital efficiency scores of the sample of 20 public hospitals in 2017 using the output-oriented DEA BCC Model.

Hospital beds - In-patient hospital care beds accommodate patients who are formally admitted (or 'hospitalized') to a hospital for treatment and/or care and who stay for a minimum of one night in the hospital. Beds in hospitals available for same-day or day-care patient care are usually not included in the inpatient but the outpatient.

Doctors – This refers to the total number of medical doctors in the hospital who graduated from Schools of Medicine (physicians, dentists, residents).

Nurses – This refers to the total number of nurses, including professional, Community Health Workers (CHW) Health Extension Officers (HEOs) who are registered to practice nursing and other clinical services.

Other staff – This refers to the total number of support staff (administrative assistants, other general staff, casuals, and lab technicians). However, data reporting doesn't specify these staff categories by profession. They are categories as support staff, casuals, and lab technicians.

4.4.2 Output Variables

Inpatient discharges and outpatient visits have been used in the literature by (Kirigia and Asbu 2013, Jarjue, Ghani et al. 2015). Based on the data availability and consistent with the literature, this study will use total inpatient discharge and total outpatient visits as the output variables. All the hospital services are consolidated by disease program and reported as total inpatient discharge and total outpatient visits. The study will use hospital data updated by the 2015 NHIS.

Total outpatient visits – It refers to the total number of patients visiting the outpatient department of the hospitals designed for diagnosis or treatment, but do not at this time require a bed or to be admitted for overnight care. These groups of patients are checked up and treated as outpatients before registering for inpatient admission.

Total inpatient discharges – This refers to the total number of patients attended and discharged. They are admitted to the hospital for further treatment and care under health personal supervision depending on the severity of the diseases.

The inpatient department consists of wards with nursing stations, beds, and all other facilities and services necessary for good health care. It is one of the important aspects that can be used as an important output for efficiency analysis for hospitals. Table 4.1 shows the details of the input and output variables used in the analysis.

Table 4. 1 Description of Input and output variables

No	Input Variables	Abbr.	Definitions or Descriptions	Units
1	Doctors	MS	Refers to total number of medical doctors in hospital who graduated from Schools of Medicine (physicians, dentists, residents).	Person
2	Nurses	NO	Total Number of nurses, including professional, Community Health Workers (CHW) Health Extension Officers (HEOs).	Person
3	Other Staffs	OS	Total Number of support staffs (administrative assistants, other general staff, casuals and lab technicians.	Person
4	Beds	BD	beds that are regularly maintained and staffed for the accommodation and full-time care of a succession of inpatients	Day
NO	Output Variables	Abbr.	Definition or Descriptions	Units
1	Outpatient visits	OPD	Total number of outpatient visits to the hospital (2017)	Visit
2	Inpatient Discharge	IPD	Total number inpatients received inpatient services and dicharged from the hospital beds in 2017	Disch

4.5 Determinants of Hospital Efficiency Using Regression Model

After the first stage of efficiency analysis from the output-oriented DEA BCC model, it is further investigated using the Tobit regression model. The technical efficiency scores of the output-oriented DEA model will be used as the dependent variable regressed against the contextual factors (environmental & institutional).

The explanatory variables for a Tobit regression model were selected based on a review of the literature (Ali, Debela et al. 2017, Sultan and Crispim 2018, Ahmed, Hasan et al. 2019) on efficiency analysis as discussed below.

4.5.1 Dependent Variable

In the second stage of DEA analysis, the Tobit regression model will investigate the contextual factors that have a significant impact on the relative efficiency of the hospitals from the initial analysis. Therefore, the inefficient scores under output-oriented DEA analysis will become the dependent variables that will regress against the other contextual factors as explanatory variables.

4.5.2 Explanatory Variable

Factors that affect the efficiency of hospitals are classified as contextual factors i.e. average length of stay (ALS), bed occupancy ratio (BOR), the ratio of bed to nurses (RoBTN), the ratio of the outpatient visit to doctors (RoOPTD), and hospital size (BED).

The following table summarises the dependent and independent variables in the second analysis using the statistical method.

Table 4. 2 shows the summary of independent and dependent variables for Tobit regression analysis

Table 4.2					
Dependent Variables	Independent Variables				
Pure Technical Efficiency (PTE)	Avearge Length of Stay (ALS)	Bed Occupancy Ratio (BOR)	Ratio of Bed to Nurses (RoBTN)	Ratio of Outpatient Visits to Doctors	Hospital Size (BED)

The average length of stay (ALS) – Average number of days patients spent in a hospital

It is calculated as follows:

$$\text{ALS} = \frac{\text{inpatient days}}{\text{admission (discharges)}}$$

Bed occupancy ratio (BOR) – Utilization of the available bed capacity. It indicates the **percentage** of **beds** occupied by patients in a defined period, usually a year. It is calculated as follows (Demir, Pulford et al. 2017);

$$\text{BOR} = \frac{\text{inpatient days}}{\text{bed days}} \text{x100}$$

Where;

inpatient days = inpatient x ALS

Bed Days = number of beds x 365 days (no of days in a year)

The **ratio of hospital beds to nurses (RoBTN)** - Total number of beds per nurse attending to in the hospital (Total number of Beds/Total number of Nurses)

The **ratio of outpatient to doctors (RoOPTD)** - Total number of outpatient visits treated per medical doctors in the hospital (Outpatient/total number of medical doctors)

Size of the hospitals (BED) – sizes are classified by the number of beds they have although there can be some variation within these groups of hospitals and medical centers.

4.6 Data Envelopment Analysis (DEA)

As discussed in the previous section, Data Envelopment Analysis (DEA) is extensively used for estimating the technical efficiency of a set of DMUs that accommodate multiple inputs and outputs. The DEA approach assumes that a set of DMUs is associated with their corresponding amount of inputs and outputs. The efficiency score of the DMU is defined as a ratio of the weighted sum of the outputs to the weighted sum of the inputs (Ahmed, Hasan et al. 2019). A DMU's efficiency score is calculated relative to an efficiency frontier. DMUs located on the efficiency frontier have an efficiency score of 1 (or 100%). And those DMUs operating beneath the frontier have an efficiency score inferior to 1 (or 100%) and hence can improve future performance. Note that no DMU can be located above the efficiency frontier because they cannot have an efficiency score greater than 100%. Those located on the frontier serve as benchmarks (peers) to inefficient DMUs. These benchmarks are associated with best practices. DEA is therefore a powerful benchmarking technique.

In estimating the efficient frontier, Charnes, Cooper, and Rhodes (CCR) (1978) assumed production as constant returns to scale (CRS) which means any level of increase in inputs will proportionally increase the level of output. However, later CCR model was modified by Banker, Charnes, and Cooper (BCC) (1984) based on the VRS which means any level of increase in inputs will not proportionally increase the level of output. In the VRS assumption, a DMU may result in IRS or DRS. These concepts will be discussed in the next part of the paper.

In reality, the health service production process is not linear. This means that CRS may not be feasible due to the presence of imperfect competition, government regulations, budget constraints, etc. that force hospitals to deviate from the efficient scale size. That was the main reason why the initial (CCR) model was modified to account for the presence of pure and scale efficiencies which caused the inefficiencies of the hospitals (Ali, Debela et al. 2017).

PNG health system including the hospitals is funded by the government and any changes in terms of government policies will always affect the allocations of health resources. That means the constant return to scale is not visible. Therefore, it is more appropriate to use the BCC model in the health service industry in PNG.

4.6.1 Model Specifications

4.6.1.1 Input/output orientation

DEA can be in the form of an output or input-oriented model depending on the firm's objective of input reduction or output maximization. In general, an input-orientated DEA model minimizes input for a given level of output. In other words, it indicates how much a firm can decrease its input for a given level of output. In the hospital analysis, the input orientation assumes that hospitals have limited control over the volume of their outputs. That means hospital management has got greater control over the use of inputs. Whereas in an output orientation, the DEA maximizes output for a given level of input. In other words, it indicates how much a firm can increase its output at a given level of input (Huguenin 2012).

However, choosing the model's orientation should be selected according to which variables (inputs or outputs) the decision-maker has the most control over. In the public sector, a decision-maker may want to maximize the output, so may choose the output orientation.

Alternatively, the government may want to reduce the input given the same output level may choose input orientation. In the context of PNG's health care system, it is fully funded by the government with counter supports from the development partners. That means the resource envelopes for the health sector are fixed through the normal budgetary system. It is therefore output orientation is more appropriate.

4.6.1.2 VRS Vs CRS Efficient Frontier

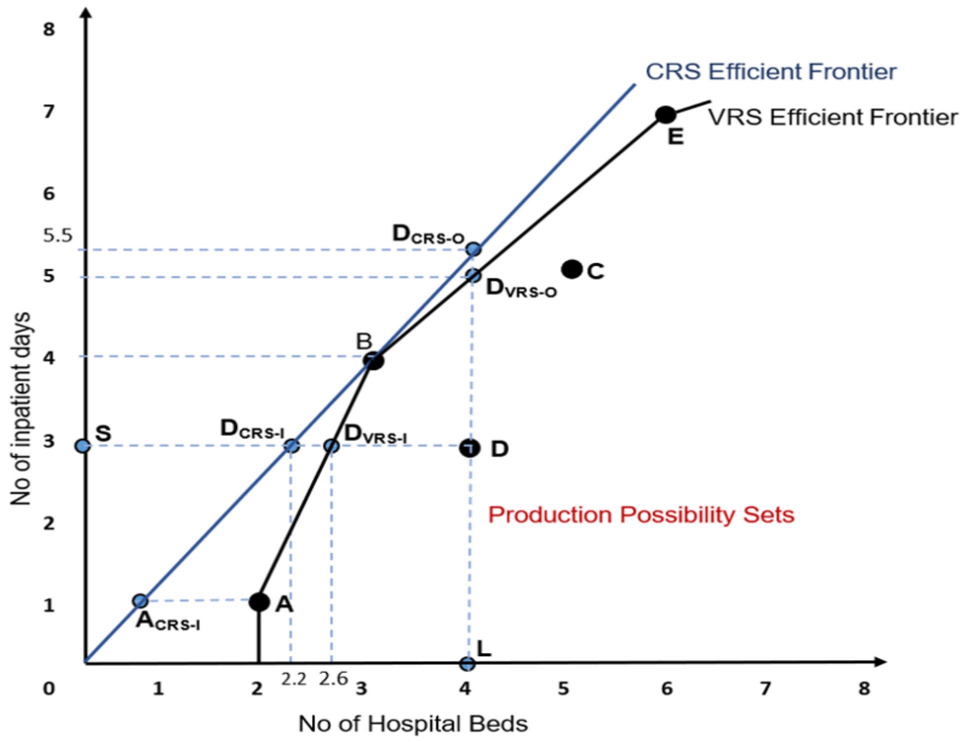
CRS and VRS efficient frontiers are based on the constant and variable return to scale model. CRS scale frontier has a linear relationship whereas the VRS has concave or convex frontiers depending on the nature of their orientations. The frontiers will be concave for the firm wishing to maximize output or convex for the firm wishing to minimize inputs.

The efficiency frontier will be different in a CRS or a VRS model. Nevertheless, within each model, the frontier will not be affected by an input or an output orientation. For example, the efficiency frontier under VRS is the same in input or output orientation. Firms located on the frontier in an input orientation is also on the frontier in an output orientation.

Figure 4.2 represents the CRS and the VRS efficient frontiers on the same graph. According to figure 4.2, letters A, B, C, D, and E represent the different sets of hospitals bounded by two efficient frontiers (CRS and VRS). Hospital B lies at an efficient point under both assumptions (CRS or VRS). This means hospital B is 100% efficient with the productivity of (4/3) 1.33 (1 hospital bed will produce 1.33 inpatient days). Hospitals A, C, D, and E are beneath the CRS efficient frontier. Meaning they are not efficient under the CRS. Their efficiency scores are less than 100%. While

Hospitals A and E are efficient under VRS which means they are 100% efficient under VRS assumptions. For hospital A to be CRS efficient, it can modify its scale and operate at $A_{CRS\text{-}I}$ to be efficient as Hospital B. The gap observed between the CRS and the VRS (ie. between A and $A_{CRS\text{-}I}$) is due to a problem of scale.

Figure 4. 2 CRS Vs VRS Efficient Frontiers under input and output-oriented DEA Model



Source: Huguenin (2012)

However, hospitals C and D are inefficient in both assumptions meaning they lie beneath both efficient frontiers. Their respective efficiency scores are inferior to 100% for both assumptions. Hospital D can either make improvements by either input-oriented or output-oriented depending on its choices. Hospital D can become VRS efficient under an input-oriented model by moving from D to D_{VRS-I} or CRS efficient by moving from D to D_{CRS-I}. On the other hand, hospital D can become VRS efficient under the output-oriented model by moving from D to D_{VRS-o} or CRS efficient by moving from D to D_{CRS-o}. Using the CRS Input-orientation, hospital D's relative technical efficiency score is equal to the distance $\mathrm{SD}_{\mathrm{CRS-I}}$ divided by the distance SD. And for output-oriented, the distance LD is divided by distance $\mathrm{LD}_{\mathrm{CRS-o}}$.

Similarly, pure technical efficiency for hospital D under the input-oriented model is the distance $\mathrm{SD}_{\mathrm{VRS-I}}$ divided by distance SD. And for the output-oriented model, pure technical efficiency is the distance LD divided by distance $\mathrm{VD}_{\mathrm{VRS\_0}}$. Note that point D is the actual production point for hospital D.

To better understand the mechanics behind DEA CRS and VRS output and input-oriented models, Table 4.3 shows a simple practical case study. It includes only one input and one output, although DEA can handle multiple inputs and multiple outputs in the output orientation. The computation of scale efficiency (SE) score for hospitals D under input and output orientations are presented. A scale efficiency score of one implies that the hospital is operating at an optimal scale or size. If the scale efficiency score is less than one, then the hospital is either too small or too big relative to its optimal size.

Table 4. 3 Calculations of TE and SE under both CRS and VRS with variables

HOSPITAL D					
Total Technical Efficiency				Scale of Efficiency	
CRS		VRS		Input Oriented	Output Oriented
Input Oriented	Output Oriented	Input Oriented	Output Oriented		
$TE = \frac{SD_{CRS-I}}{SD}$ $= \frac{2.2}{4}$ $= 0.55$ $= 55\%$	$TE = \frac{LD}{LD_{CRS-o}}$ $= \frac{3}{5.5}$ $= 0.545$ $= 54.5\%$	$PTE = \frac{SD_{VRS-I}}{SD}$ $= \frac{2.6}{4}$ $= 0.65$ $= 65\%$	$PTE = \frac{LD}{LD_{VRS-o}}$ $= \frac{3}{5}$ $= 0.60$ $= 60\%$	$SE = \frac{SD_{CRS-I}}{SD_{VRS-I}}$ $= \frac{2.2}{2.6}$ $= 0.846$ $= 84.6\%$	$SE = \frac{LD_{VRS-o}}{LD_{CRS-o}}$ $= \frac{5}{5.5}$ $= 0.909$ $= 90.9\%$

Interpretations:

Under CRS DEA Model, the technical efficiency scores for hospital D under input-orientation can reduce input by (100-55) 45% (hospital bed) to be efficient and produced the same level of output at 3 inpatient days. Similarly, for output orientation, the Technical efficiency for hospital D can increase output by (100-54.5) 45.5% given the same level of input (4 hospital beds). In reality, these answers will always be equal.

However, under the VRS input-oriented model, hospital D's efficiency score is 65%. This means that hospital D can reduce (100-65) 35% of inputs (beds) while maintaining the output level given at 3 inpatient days. Similarly, under the VRS output-oriented model, the efficiency score of hospital D is 60%. That means Hospital D could increase its output by (100-60) 40% given the same level of inputs at 4 hospital beds. This indicates that the resources (beds) have been underutilized. They could have produced five inpatient days if it was fully utilized given the current input level to be efficient.

For Scale efficiency, the answers for input and output orientations are less than 1 (100%). Thus, hospital D is either too small or too big relative to its optimal size.

4.6.2 Output-oriented DEA CCR and BCC Model

4.6.2.1 DEA CCR Model

DEA began with Edwardo Rhodes's Ph.D. dissertation research at Carnegie Mellon University. This work by Charnes, Cooper, and Rhodes originated in the early 1970s with the introduction of the CCR model. The CCR model was named after Charnes, Cooper, and Rhodes (1978) and it's based on the production that is a constant return to scale (CRS).

In CCR Model, DEA measure the efficiencies of the hospitals with multiple inputs and outputs. The ratio of weighted inputs and outputs is calculated to produce a score that is then compared to that of the best-performing hospital. This score can also be referred to as relative efficiency censored between 0 and 1. The hospitals that have a ratio of less than 1 are less efficient relative to the most efficient unit. Therefore, what DEA does is to consolidate different units of hospitals at different locations, environments, or varies in terms of inputs components. Note that the hospital is based on the principle that the performance of each inefficient hospital must be compared relative to the 'best-practice frontier, which is a benchmark that envelopes all other hospitals on the production possibility. In this method, any deviation from the 'best-practice frontier must be an indication of technical inefficiency. It is important to identify the technical inefficiencies of inefficient hospitals and make improvements by giving weightings to make every hospital relatively efficient.

Following Charnes, Cooper, and Rhodes (CCR) the technical efficiency of a hospital can be expressed as a maximum ratio of the total sum of weighted outputs to the total sum of weighted inputs. That is:

$$Efficiency = \frac{weighted\ sum\ of\ hospital\ output}{weighted\ sum\ of\ hospital\ input} \qquad (1)$$

Assuming that there are *n* hospitals, each with *m* hospital inputs and *s* hospital outputs, the relative efficiency score of a given hospital *(TE_0)* is obtained by solving the following output-orientated CCR model. To maximize the efficiency of the objective function as the best practice DMU on the frontier as represented by equation (2) is subject to the constraints of the rest of the DMUs is less than or almost equal to 1 is represented below;

$$\max TE_0\,(u,v) = \left(\frac{\sum_{r=1}^{s} \mu_r y_{r0}}{\sum_{i=1}^{m} v_i x_{i0}} \right) \qquad (2)$$

$$Subject\ to: \left(\frac{\sum_{r=1}^{s} \mu_r y_{rj}}{\sum_{i=1}^{m} v_i x_{ij}} \right) \leq 1; j = 1, 2, \ldots, n$$

$$u_i \geq 0; i = 1, 2, \ldots, m;$$

$$v_r \geq 0; r = 1, 2, \ldots, s;$$

Where:

TE_0 = the efficiency score of hospital 0;

Z_{ij} = the amount of health system input *i* utilized by the j^{th} hospital;

y_{rj} = the amount of health system output *r* produced by the j^{th} hospital;

u_i = weight given to health system input *i*;

v_r = weight given to output *r*

If the denominator $(\sum_{i=1}^{m} u_i x_{i0} = 1)$ of equation (2) of the hospital is equal to one, the transformed linear programming model for hospital 0 can be written as follows;

$$\max TE_0 = \sum_{r=1}^{s} v_r y_{r0}$$
$$subject\ to: \sum_{r=1}^{s} v_r y_{rj} - \sum_{i=1}^{m} u_i x_{ij} \leq 0; j = 1,2,\ldots,n \qquad (3)$$
$$\sum_{i=1}^{m} u_i x_{i0} = 1$$
$$u_i \geq 0; i = 1,2,\ldots,m$$
$$v_r \geq 0; r = 1,2,\ldots,s$$

This CCR Model assumes a constant return to scale which means all observed production combinations can be scaled up or down proportionally. In other words, the changes in inputs will have proportionally equal changes in the output productions.

4.6.2.2 DEA BCC Model

BCC model is the modification of the CCR model by Banker, Charnes, and Cooper (1984) assuming that production is a VRS (Jarlue, Nor, Ghani & Jalil, 2015). Again, the BCC model was named after the initials of the authors (Banker, Charnes, and Cooper). BCC model is based on the variable returns to scale and the technical efficiency obtained eliminates the effect of scale, so it is called “pure technical efficiency”.

In reality, there are three (3) scenarios that exist when the hospital utilizes the inputs into outputs productions. These include CRS where output increase proportional to the input increase, increasing return to scale (IRS) where output increase more than input increase, and decreasing return to scale (DRS) where output increase less than the input increases depending on whether the hospital is experiencing economies of scale or diseconomies of scale (Kirigia and Asbu 2013).

The Charnes, Cooper, and Rhodes (CCR) model, in reality, does not have a state of the optimal scale of production. This is because the technical efficiency of the CCR model also contains the component of scale efficiency. The CRS could not, however, be applied since hospitals were not operating at an optimal scale. So, it was a necessity to decompose technical efficiency into pure technical efficiency and scale efficiency. To separate scale efficiency from technical efficiency, a DEA model with variable returns to scale was applied (Awara and Susan 2019).

Hence, the VRS model isolates the pure technical efficiency component and scale efficiency which is related to the size or structure of the decision-making unit (DMU). Sometimes the inefficiencies are caused by the size of the hospitals. The hospital may be too large for the volume of activities that it is conducting; and therefore, may experience *inefficiencies of scale*. Conversely, a hospital may be too small for its level of operation, and thus experience *efficiencies of scale*. Inefficiency is due to too many inputs (workforce, capitals, etc.) leading to decreased output or what is commonly known as inefficiencies of scale which to some extend are realistic assumptions for a developing country like PNG (Akazili, Adjuik et al. 2008).

The output-oriented BCC model can be estimated as follows:

$$\max TE_0(\mu, v) = \sum_{r=1}^{s} \mu_r y_{ro} + u_0 \quad .$$

$$\begin{aligned}
&\text{Subject to:} \\
&\sum_{i=1}^{m} v_i x_{ij} = 1 \\
&\sum_{r=1}^{s} \mu_r y_{ro} - \sum_{i=1}^{m} v_i x_{ij} + u_0 \leq 0, j = 1, 2, \ldots, n \\
&\mu_r \geq \varepsilon, r = 1, 2, \ldots, s \\
&v_i \geq \varepsilon,\ i = 1, 2, \ldots, m \\
&u_0 \text{ is unconstrained in sign.}
\end{aligned} \qquad (4)$$

Where:

ε = is an infinitesimal non-Archimedean quantity greater than zero.

A value of $u_0 > 0$ implies increasing returns to scale;

$u_0 < 0$ means decreasing returns to scale, and

$u_0 = 0$ denotes constant returns to scale.

Under the DEA BCC model, it is possible to analyze whether a hospital's production indicates an IRS, CRS, or DRS by the sign of the variable u_0 (equation 4) above. A value of $u_0 > 0$ implies IRS; $u_0 < 0$ means DRS, and $u_0 = 0$ denotes CRS. Therefore, this BCC model permits both the separation of technical and scale efficiencies and the determination of whether an individual hospital's operations were in regions of IRS, CRS, or DRS.

To identify the relative technical efficiency scores of all the hospitals in the sample, the equation (4) above will be run 20 times because we have a sample size of 20 hospitals. DEA by default assigns weights to each hospital's inputs and to maximize the efficiency scores of the hospitals. A hospital is considered to be technically efficient if it scores one, implying 100% relative technical efficient, whereas a score of less than 1 implies that it is relatively technically inefficient, compared to peers in its efficiency reference set.

In practice, the application of the CCR model may not be feasible due to government regulations, budget constraints, etc. which force the hospitals to deviate from the optimal scale (Ali, Debela et al. 2017). It was further highlighted by (Jarjue, Ghani et al. 2015) that under the CCR model, hospitals do not operate on an optimal scale. It produces technical efficiency scores that are contaminated by scale efficiencies. In other words, it does not identify and separate the inefficiencies caused by the presence of scale.

Furthermore, Ahmed et al. (2019), Mujasi et al., (2016), mentioned that the health services production process is not linear meaning it's not constant and thus, VRS technical efficiency assumption is more appropriate. They also stated that when hospitals are given a fixed quantity of inputs, managers are expected to produce as much output as possible. Hospital managers do not have the administrative power to make any decisions on hospital resources if they need extra resources including staffing. For these reasons, the output-oriented BCC Model is used to estimate and capture the magnitude of the scale effect.

Similarly, in the context of the PNG health system, public hospitals are owned by the government with limited private ownership. The funding and other resources for the hospitals are provided in fixed quantity through the normal annual budgetary process. The staffing and bedding capacities of each public hospital are determined centrally by the government through the National Department of Health according to the NHSS. The individual hospital managers do not have any control over the size of the health workforce or any resources allocated for the hospitals in this matter. They managed what is appropriated and allocated to them. Therefore, it is more appropriate and applicable for this study to use the output-oriented BCC DEA model.

4.7 One-Sample t-Test

One sample t-test is a statistical procedure often performed for testing the mean value of a distribution. It can be used under the assumption that sampled distribution is normal. For large samples, the procedure often performs well even for non-normal populations. In this case, the t-test will be conducted to examine the average value of the inefficient score is no different from the population mean. In other words, the average value of the score will be compared with the population mean and make a statistical decision as to whether or not the sample mean is different from the population mean.

Hence, the t-test was used in the study to test whether there is technical inefficiency in the hospitals and that is to test whether the mean score of technical inefficiency is zero. The inefficiency scores from the output-oriented BCC model were used for this testing. To know whether the average value of the inefficient scores of the sampled hospitals differ from the population mean, one-sample t-test was conducted by firstly setting up the Null hypothesis (Ho) and Alternative hypothesis (Ha) for the population mean.

Ho: μ = 0, assumes that the mean score of the inefficient scores is no different from zero.

Ha: μ ≠ 0, assumes that means score of the technical inefficiency scores of the hospitals is not equal to 0.

Mathematically, the t-test can be calculated in the following methods:

1. Calculate the standard deviation for the sample by using this formula:

$$s = \sqrt{\frac{\sum\left(x_i - \bar{x}\right)^2}{n-1}}$$

Where,

S = Standard deviation

$\bar{X}$ = sample means

n = number of observations in the sample

2. Calculate the value of the one-sample t-test, by using this formula:

$$t = \frac{\bar{X} - \mu}{S}\sqrt{n}$$

Where,

t = one sample t-test value

μ = population mean

3. Calculate the degree of freedom by using this formula:

   V = n - 1

   Where,

   V= degree of freedom

In hypothesis testing, statistical decisions are made to decide whether or not the average value of the inefficient scores is different from 0. The decision to reject or fail to reject the Null hypothesis is decided depending on the t-value and the p-value.

If the p-value is greater than the level of confidence (99% use in this study) then the null hypothesis is failed to reject. If the p-value is less than the level of confidence (99%) then will reject the null hypothesis and accept the alternative hypothesis. Fail to reject the null hypothesis implies that hospitals have no inefficiencies. On the other hand, rejecting the null hypothesis implies inefficiencies in the hospitals, and necessary recommendations must be made following the DEA analysis on the input and output changes required for improvements on performance efficiencies

4.8 Tobit Regression Model

The result from the DEA for hospital efficiencies can be extended to the second stage of the analysis using the Tobit regression model. The Tobit model was first developed in Tobin's pioneering work (1958) on households to measure and estimate the linear relationship between variables (independent and dependent). In the second stage of the analysis of hospital efficiency, it is desired to shed more light on the issue of the possible impact on the efficiency by the contextual factors which are beyond the control of the hospital administration.

One might think ordinary least squares (OLS) can be used with the assumption that the error terms are normally distributed and homoscedasticity. The efficiency scores calculated in the first stage with the DEA model have censoring points at zero and one. It is assumed that because OLS has normal distribution and homoscedasticity, it is unlikely to be used in this case. The dependent variable would likely to produce biased and inconsistent parameter estimates because the expected error will not be equal to zero. It doesn't consistent with the DEA censored efficiency scores. Therefore, Tobit regression models were used instead to identify the contextual factors that have a significant influence on the productive efficiency of hospitals. The technical efficiency scores from the first stage of the output-oriented DEA BCC Model analysis were regressed against the contextual factors in this regard.

According to the literature, some of the common factors that impact the efficiencies of the hospitals include catchment population, distance, location (urban/rural), ownership, teaching status, the average length of stay, outpatient visits as a proportion of inpatient days, etc. (Kirigia and Asbu 2013).

In this study, due to data limitations, the possible independent contextual factors as a continuous variables were; BOR (bed occupancy rate), ALS (average length of stay), RoBTN (ratio of bed to nurses), RoOPTD (ratio of outpatient visits to doctors) and number of BEDs to indicate the hospital size as a dummy (the qualitative variable) which will be regressed against the technical inefficiency scores to examine how these factors may affect the inefficiency of the hospitals.

The censored Tobit model was used since the dependent variable is censored from zero (0). Similar to the studies of (Kirigia and Asbu 2013, Ali, Debela et al. 2017), this study also used the DEA scores that transformed into inefficiency scores using the following formula:

$$\text{Inefficiency Scores} = \left(\frac{1}{\text{DEA TE Score}}\right) - 1$$

The Tobit regression model is applicable in cases where the dependent variable is constrained in some ways, in this case, its constraints to lie above 0. The censored Tobit regression model could be determined as follows:

$$\begin{aligned} y^* &= \beta_i x_i + \varepsilon_i \\ y_i &= y_i^* \quad if \;\; y_i^* > 0 \\ y_i &= 0 \;\; if \; y_i^* \leq \; 0 \\ & \quad i = 1, 2, \ldots, N \end{aligned}$$

Where

N - is the number of observations

$\varepsilon t \sim N(0, \sigma^2)$ – meaning error term is normally distributed with 0 mean and same variance

Y_i^* - unobserved latent variable and y_i stand for transformed DEA VRS efficiency scores for hospital i.

β_i - is the vector of unknown parameters which determines the relationship between the independent variables and the latent variable with relevant sign

x_i - set of explanatory/independent variables for hospital i

εt - an independently distributed stochastic/random error term assumed to be normally distributed with zero mean and same variance σ^2

According to (Awara & Susan, 2019) once the DEA scores are changed into inefficiency scores, the Tobit model coefficients can be interpreted similarly as that of ordinary least squares regression. So, the initial regression model containing these inefficiency scores as the dependent variable with the contextual factors are generated as follows:

$$Ineff = \alpha + \beta_1 ALS + \beta_2 BOR + \beta_3 RoBTN + \beta_4 RoOPTD + \beta_5 BED + \varepsilon i$$

Where;

Ineff: Inefficiency scores for the hospitals

B_0: is the constant term

β_1: Coefficient of ALS (average length of stay)

β_2: Coefficient BOR (bed occupancy rate)

β_3: Coefficient of RoBTN (ratio of bed to nurses)

β_4: Coefficient of RoOPTD (ratio of outpatient visits to doctors)

B_5: Coefficient of BED (Size) dummy indicating 1= big size (beds > 247.2) and 0 = small size (BED ≤ 247.2).

εi: is the stochastic/random error term.

Tobit Regression will be done through Stata software.

4.8.1 Hypothesis

By estimating the empirical model, we wished to test two hypotheses:

Firstly, to test the overall significance of the model, we state the joint null hypothesis to find out is there any significance or what's the use of keeping them in the model;

H_0: $\beta_1 = \beta_2 = \beta_3 = \beta_4 = \beta_5 = 0$

and an alternative or research hypothesis is;

H_A: at least a parameter is not equal to zero.

The H_0 is directed towards insignificance. If it is unable to reject the H_0, meaning we don't have sufficient evidence to support the **Ho** then will reject Ho and accept the H_A.

The selected empirical model based on the Chi-Square method is:

$$Ineff = \alpha + \beta_1 ALS + \beta_2 BOR + \beta_3 RoBTN + \beta_4 RoOPTD + \beta_5 BED + \varepsilon i$$

Secondly, β_n is not significantly different from zero in either direction. Thus, the null (H_0) and alternative hypotheses (H_A) are: H_0: $\beta_n = 0$; and H_A: $\beta_n \neq 0$. The alternative hypothesis not equal to 0 (H_A: $\beta_n \neq 0$) means that it could be greater or less than 0 depending on their relationships with the dependent variables (**Ineff**).

The individual null hypotheses are tested using the t-distribution test. So the hypothesis can be identified firstly by looking at whether contextual factors have any relationships with the inefficiency scores. The study expected that ALS and RoBTN have positive relationships with inefficiency scores while the rest of the factors BOR, RoOPTD, and BED have negative relationships with inefficiency scores.

Therefore, the individual hypotheses are given below;

H_0: $\beta_1 = 0$

H_A: $\beta_1 > 0$ Coefficient of ALS is positive meaning $\beta_1 > 0$ in H_A.

H_0: $\beta_2 = 0$

H_A: $\beta_2 < 0$ Coefficient of BOR is negative meaning $\beta_2 < 0$ in H_A.

H_0: $\beta_3 = 0$

H_A: $\beta_3 > 0$ Coefficient of RoBTN is positive meaning $\beta_3 > 0$ in H_A

H_0: $\beta_4 = 0$

H_A: $\beta_4 < 0$ Coefficient of RoOPTD is negative meaning $\beta_4 < 0$ in H_A

H_0: $\beta_4 = 0$

H_A: $\beta_5 < 0$ Coefficient of BED is negative meaning $\beta_5 < 0$ in H_A

So, the final empirical model should be:

$$Ineff = \alpha + \beta_1 ALS - \beta_2 BOR + \beta_3 RoBTN - \beta_4 RoOPTD - \beta_5 BED + \varepsilon i$$

To estimate the regression coefficients (β_i), we applied the maximum likelihood estimation (MLE) method in Tobit regression. Regression coefficients were interpreted similarly to that of OLS regression. However, the only difference was the interpretation of the coefficient. The negative sign means better efficiency and the positive sign means more inefficiency (Sultan and Crispim 2018).

CHAPTER V: RESULTS AND DISCUSSIONS

Health system strengthening is important for improving the health care system of a country. One of the approaches is through enhancing efficiency in the utilization of existing resources to ensure the greatest health benefit is attained. Improving efficiency is important at all levels of facilities. However, hospital services consume a substantial amount of health resources.

This chapter presents the results from the DEA and censored Tobit regression analysis for the observation of 20 public hospitals in PNG. The data for the study was collected for 2017. The discussions is introduced by the descriptions of the input and output variables used in the study followed by DEA and Tobit regression analysis.

The DEA method was discussed in two (2) perspectives. Firstly, it estimated the efficiency of the hospitals and explained their inefficiency scores. The results were presented and discussed using both input and output-oriented DEA BCC model. The discussions began with an input-oriented BCC Model in terms of technical, pure, and scale efficiency scores. However, in-depth discussions were done using the output-oriented DEA BCC model to be consistent with the objective of this study. Secondly, the study presented the result of the t-Test distribution on the inefficiency scores. This result confirmed the presence of inefficiencies in the PNG hospitals followed by determining the level of output increases or input reductions that were required for inefficient hospitals to become relatively efficient. Finally, the results of the Tobit regression analysis for the contextual factors impacting the efficiencies of the hospitals were analyzed, presented, and discussed. In this analysis, the inefficiency scores generated in the first analysis using the output-oriented BCC Model were used as the dependent variable.

5.1 Rationale of Reporting both input and output-oriented model

It was assumed that there is no difference between the efficiency of hospitals based on its orientation i.e. either input-oriented or output-oriented. The frontier is not affected by an input or an output orientation. For example, the efficiency frontier under VRS will be the same in input or output orientation. Firms located on the frontier in an input orientation will also be on the frontier in an output orientation. Huguenin, (2012) and Rajasekar & Deo, (2014) compared input-oriented with output-oriented results that there were no efficiency differences identified. The technical efficiency scores had the same values in input or an output orientation except for slight differences according to the model's orientation when VRS is assumed

Therefore, the current study included both orientations to compare and identify any differences in efficiency scores that exist under the input and output orientation model in PNG. Possible observations and the existence of the differences in both models may provide contradicting results to the existing literature.

5.2 Descriptive analysis of inputs and outputs

Table 5.1 shows the descriptive statistic of the inputs and output variables used in the analysis. There were (4) inputs which include the number of beds, number of doctors, number of nurses, and other staff. The output includes total inpatient discharges and total outpatient visits for the study observation of 20 hospitals in 2017.

Table 5. 1 Descriptive statistics of inputs and output variables

	Output Variables		Input Variables			
	IP Discharge	*OP Visits*	*Beds*	*Doctors*	*Nurses*	*Other Staffs*
Mean	5,531	38,846	247	19	167	98
Standard Deviation	4,991	18,350	241	13	108	160
Minimum	113	3,773	19	2	37	15
Maximum	19,613	71,318	1,096	50	442	757
Sum	110,610	776,917	4,944	371	3,331	1,965
Observations	20	20	20	20	20	20

The hospitals had a total of 110,610 inpatient discharges and 776,917 outpatient visits. These outputs have been produced using the inputs (4,944 beds, 371 doctors, 3,331 nurses, and

1,965 Other Staffs). There was wide variation in both inpatient discharge and outpatient visits across the hospitals. The inpatient discharges ranged from 113 received by Laloki Hospital to 19,613 as the highest number of patients received by Port Moresby General Hospital. The average inpatient was around 5,531 with a standard deviation of 4,991.

Correspondingly, outpatient department visits varied from a minimum of 3,773 produced by Kerema Hospital to a maximum of 71,318 from Kimbe Hospital. The average outpatient visit was around 38,846 with a standard deviation of 18,350

Similarly, there was a significant variation among the number of input variables. The minimum number of hospital beds ranging from 19 (Daru Hospital) to 1,096 (Port Moresby General Hospital) with an average value of 247 and a standard deviation of 241. Kerema Hospital has the lowest number of doctors with only 2 while Angau Hospital has the highest with 50 and an average value of 19 and a standard deviation of 13.

Nurses ranged from 37 with Popodetta Hospital to 442 nurses with Port Moresby General Hospital with an average value of 167 and a standard deviation of 108.

And finally, Laloki has the lowest number of Other Staffs (15) while Port Moresby still maintained the highest with 757 other staff.

5.3 Empirical Results from the DEA

The performances of hospitals in PNG were measured by DEA using all three measurement approaches which include CRS, VRS, and Scale Efficiency. The results obtained from these three assumptions (CRS, VRS, and SE) were discussed and presented below. The results in terms of technical efficiency scores were computed and obtained using the DEAP 2.1 software. They have then converted to Excel spreadsheets for further analysis relevant to the discussions.

It is important to remember that efficiency scores range from 0 to 1 (100% TE). Hospitals with scores of 1 are technically more efficient than those with less than 1 (less efficient). This means any hospital with an efficiency score of less than 1 is referred to as inefficient and hence needs to improve their performance.

5.3.1 Input oriented DEA-BCC Model

BCC Model is more flexible as it relaxes the assumption of CRS to allow for VRS. In this section, the results from the input-oriented variable return to scale and scale efficiencies are presented. In an input orientation, DEA minimizes input for a given level of output; in other words, it indicates how much a firm can decrease its input for a given level of output.

Table 5.2 presents the technical efficiency, pure technical efficiency, and scale efficiency scores of the 20 public hospitals in PNG. It also presents the overall descriptive statistics (sum, minimum, maximum, mean, and standard deviation) for inputs and outputs of the hospitals. Towards the end of the table shows the mean and standard deviation of the efficiency scores of the inefficient hospitals.

Table 5. 2 Input oriented DEA CRS, VRS, and SE of the hospitals

HOSPITAL	CRS	VRSTE	SE	RTS
ALOTAU HOSPITAL	0.486	0.496	0.979	drs
MENDI HOSPITAL	0.568	0.634	0.896	irs
KUNDIAWA HOSPITAL	0.583	0.634	0.920	drs
KAVIENG HOSPITAL	0.572	0.644	0.887	irs
WABAG HOPITAL	0.612	0.667	0.917	irs
BORAM HOSPITAL	0.743	0.835	0.890	drs
MADANG HOSPITAL	0.849	0.852	0.997	irs
KEREMA HOSPITAL	0.238	1	0.238	irs
LALOKI HOSPITAL	0.382	1	0.382	irs
ANGAU BASE HOSPITAL	0.729	1	0.729	drs
NONGA BASE HOSPITAL	0.941	1	0.941	drs
BUKA HOSPITAL	1	1	1	-
DARU HOSPITAL	1	1	1	-
GOROKA BASE HOSPITAL	1	1	1	-
KIMBE HOSPITAL	1	1	1	-
LORENGAU HOSPITAL	1	1	1	-
MOUNT HAGEN HOSPITAL	1	1	1	-
POPONDETTA HOSPITAL	1	1	1	-
PORT MORESBY GENERAL	1	1	1	-
VANIMO HOSPITAL	1	1	1	-
Overall mean, standard deviation, minimum and maximum scores				
Mean	0.785	0.888	0.889	
Standard Deviation	0.247	0.171	0.210	
Minimum	0.238	0.496	0.238	
Maximum	1	1	1	
Observation	20	20	20	
Mean and standard deviation of efficiency scores from inefficeint hospitals				
Mean	0.609	0.680	0.798	
Standard Deviation	0.202	0.125	0.253	

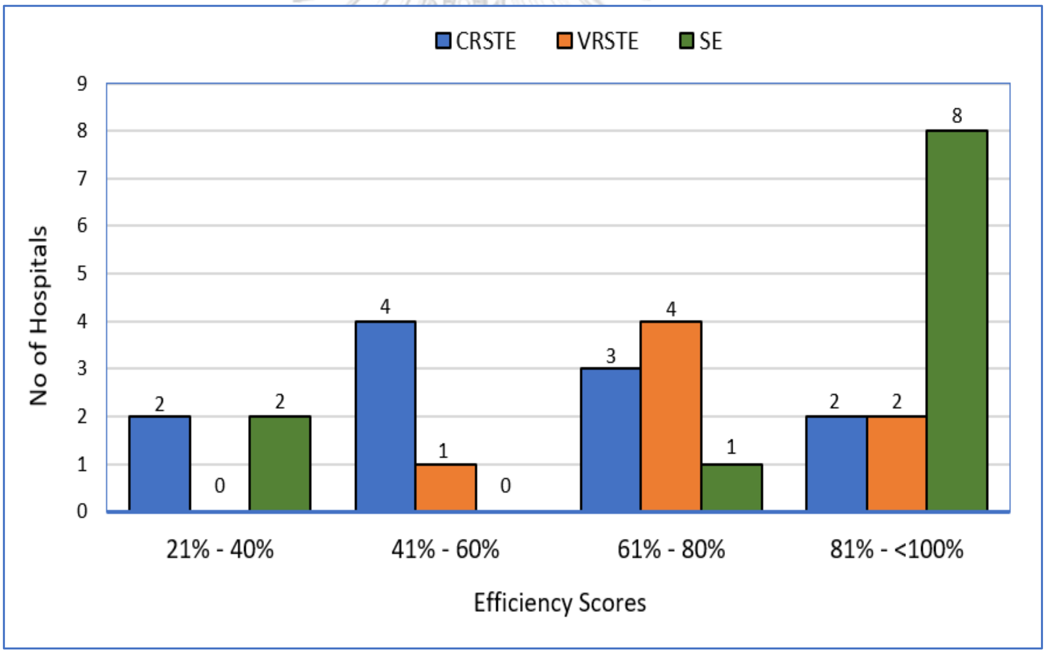
5.3.1.1 Technical Efficiency

As estimated under the CRS frontier, 9 (45%) of the 20 hospitals were technically efficient, implying that they were efficient (both pure technical and scale efficiency). A percentage change in inputs is accompanied by the same percentage change in outputs. The remaining 11 (55%) were relatively inefficient, having technical efficiency scores less than 100%.

The results for CRS technical efficiency scores showed a wide variation between efficient and inefficient hospitals with a minimum of 24% to a maximum of 100%. The mean overall technical efficiency score was 0.79 (79%) with a standard deviation of 0.25 (25%).

Figure 5.1 shows the frequency distributions of the inefficient hospitals by the efficiency scores under constant returns to scale technical efficiency (CRSTE), variable returns to scale technical efficiency (VRSTE) and scale efficiency (SE) from the 20 hospitals analyzed using the input-oriented DEA model.

Figure 5. 1 Distribution of CRSTE, PTE & SE of the inefficient hospitals



As reflected in figure 5.1, the distribution of the CRSTE scores of the hospitals was done as follows; 2 hospitals had technical efficiency scores between 21% - 40%, 4 hospitals had technical efficiency scores between 41% - 60%, 3 hospitals had technical efficiency scores between 61% - 80% and 2 hospitals had technical efficiency scores between 81% - <100%. It was identified that Kerema and Laloki Hospital had the lowest technical efficiency scores of 0.24 (24%) and 0.38

(38%) respectively. The average CRSTE score of the inefficient hospitals is 0.61 (61%) with a standard deviation of 0.2 (20%). This means that the inefficient hospitals could reduce their inputs by (100-61) 39%. In other words, inefficient hospitals could reduce their inputs by 39% without reducing the levels of the outputs in terms of inpatient discharge and outpatient visits.

5.3.1.2 Pure Technical Efficiency

Under VRS analysis (refer to table 5.2), 13 (65%) out of 20 hospitals were VRS technically efficient since they had relative efficiency scores of 100%. The remaining 7 (35%) hospitals were VRS technically inefficient meaning relative technical efficiencies of less than 100%. Among the inefficient hospital (refer to fig. 5.1), 1 hospital had technical efficiency scores between 41% - 60%, 4 hospitals had technical efficiency scores between 61% - 80%, and another 2-hospital had technical efficiency scores between 81% - <100%. The inefficient hospitals had an average score of 68% with a corresponding standard deviation of 13%. This implied that on average the inefficient hospital could reduce their utilization of inputs by (100-68) 32% without reducing the output.

5.3.1.3 Scale Efficiency

On the other hand, (refer to table 5.2), out of the 20-hospital analyzed 9 (45%) hospitals were scale efficient whereas the remaining 11 (55%) were scale inefficient. Among the inefficient hospitals, (refer to fig. 5.1) 2 hospitals had scale efficiency scores between 21% - 40%, 1 hospital had scale efficiency scores between 61% - 80%, and 8 hospitals had scale efficiency scores between 81% - <100%.

The inefficient hospitals had an average scale score of 80% with a standard deviation of 25%. This implies that, on average, the scale inefficient hospitals could produce their current output levels with (100-80) 20% less capacity than they were using.

The nine scale-efficient hospitals operated under CRS implied that these hospitals were operating at their most productive scale sizes. Among the 11 inefficient hospitals, 6 hospitals had an IRS, while the remaining 5 hospitals were operating on DRS. For the inefficient hospital to be efficient and more productive, those 6 hospitals with IRS should expand both their outputs and inputs (scale of operation). Similarly, those 5 hospitals with DRS could downsize the scale of operation through input and output reductions.

5.3.2 Output oriented DEA-BCC Model

It is important to recall that an output-oriented DEA maximizes output for a given level of input; in other words, it indicates how much a hospital can increase its output for a given level of input. The model's orientation is selected according to which variables (inputs or outputs) the decision-maker has the most control over. For example, the PNG Health System is mainly subsidized by the government through the government system. That means all the inputs in the study are allocated in fixed quantities. It is, therefore, more appropriate for the current study to use the output-oriented DEA model to measure the efficiency of the hospitals.

In DEA, one of the important parts of the investigation is to identify and locate the set of efficient hospitals that set a benchmark for relatively inefficient hospitals (Jahanshahloo, Shirzadi et al. 2007). It is discussed in more detail later in the section (Scope for output increases/input reductions).

Table 5.3 shows the individual hospital DEA scores for CRSTE, VRSTE scale efficiency (SE), and returns to scale (RTS). The table also shows the efficiency reference set for each inefficient hospital. The end of the table shows the overall descriptive statistics (mean, standard deviation, minimum, maximum, etc.) of the CRSTE, VRSTE, and SE scores.

Table 5. 3 Output Oriented DEA CRS, VRS, and SE scores of the hospitals

DMUs (Hospitals)	Efficiency Scores			RTS	Reference Set (Limbda Weights)
	CRS	VRSTE	SE		
ALOTAU HOSPITAL	0.486	0.744	0.654	drs	Kimbe (0.415), Vanimo (0.398), Mt Hagen (0.188)
ANGAU BASE HOSPITAL	0.729	1	0.729	drs	
BORAM HOSPITAL	0.743	0.928	0.801	drs	Kimbe (0.045), Angau (0.284), Goroka Base (0.061), Popodetta (0.610)
BUKA HOSPITAL	1	1	1	-	
DARU HOSPITAL	1	1	1	-	
GOROKA BASE HOSPITAL	1	1	1	-	
KAVIENG HOSPITAL	0.572	0.602	0.949	drs	Popondetta (0.704), Kimbe (0.090), Lorengau (0.206)
KEREMA HOSPITAL	0.238	1	0.238	irs	
KIMBE HOSPITAL	1	1	1	-	
KUNDIAWA HOSPITAL	0.583	0.854	0.682	drs	Mt Hagen (0.365), KImbe (0.406), Vanimo (0.229)
LALOKI HOSPITAL	0.382	1	0.382	irs	
LORENGAU HOSPITAL	1	1	1	-	
MADANG HOSPITAL	0.849	0.858	0.990	drs	Goroka Base (0.464), Kimbe (0.461), Lorengau (0.075)
MENDI HOSPITAL	0.568	0.689	0.824	drs	Angau Base (0.084), Kimbe (0.040), Popodetta (0.876)
MOUNT HAGEN HOSPITAL	1	1	1	-	
NONGA BASE HOSPITAL	0.941	1	0.941	drs	
POPONDETTA HOSPITAL	1	1	1	-	
PORT MORESBY GENERAL	1	1	1	-	
VANIMO HOSPITAL	1	1	1	-	
WABAG HOPITAL	0.612	0.670	0.913	drs	Goroka Base (0.074), Vanimo (0.721), Buka (0.205)
Mean	**0.785**	**0.9173**	**0.8552**		
Standard Deviation	**0.247**	**0.1336**	**0.2202**		
Minimum	**0.238**	**0.602**	**0.238**		
Maximum	**1**	**1**	**1**		
Observation	**20**	**20**	**20**		

CRS - Constant Return to Scale, VRS - Variable Return to Scale, SE - Scale Efficiency, RTS - Return to Scale,

drs - decreasing return to scale, irs - increasing return to sacle

5.3.2.1 Results from the t-Distribution Test

This section presents the results from the t-distribution test on the inefficiency scores. Table 5.4 showed the stata results for one sample t-test for variable return to scale technical inefficiency scores. The observation was 20, the estimated sample mean was 0.12 with the standard deviation of 0.20 and at-value of 2.56. The hypothesis test was conducted using the 99% level of confidence. There were 3 possible alternatives provided in the results. It showed that the mean value of the inefficacy score distribution was not equal to zero, which means it's more or less than zero. However, this study concerned only the results from the right tail test as it was expecting better average scores.

The one-sample t-test statistic is 2.5993 and the p-value is 0.0088 which was less than 0.01 (P-value < 0.01). Such a p-value indicated that the average mean of the inefficient scores was statistically significantly different from 0. Therefore, it concluded that the null hypothesis was rejected at a 99% confidence level. This implied that there was technical inefficiency in the hospitals in PNG. This confirmed the presence of technical inefficiency which required further analysis and recommendations for improvements in the next part of the discussions.

Table 5. 4 One sample t-test for the inefficiency scores

```
. ttest VRSTIE == 0, level(99)

One-sample t test
------------------------------------------------------------------------------
Variable |     Obs        Mean    Std. Err.   Std. Dev.   [99% Conf. Interval]
---------+--------------------------------------------------------------------
  VRSTIE |      20     .118159    .0454576    .2032927   -.0118923    .2482102
------------------------------------------------------------------------------
    mean = mean(VRSTIE)                                           t =   2.5993
Ho: mean = 0                                     degrees of freedom =       19

    Ha: mean < 0                 Ha: mean != 0                 Ha: mean > 0
 Pr(T < t) = 0.9912         Pr(|T| > |t|) = 0.0176          Pr(T > t) = 0.0088
```

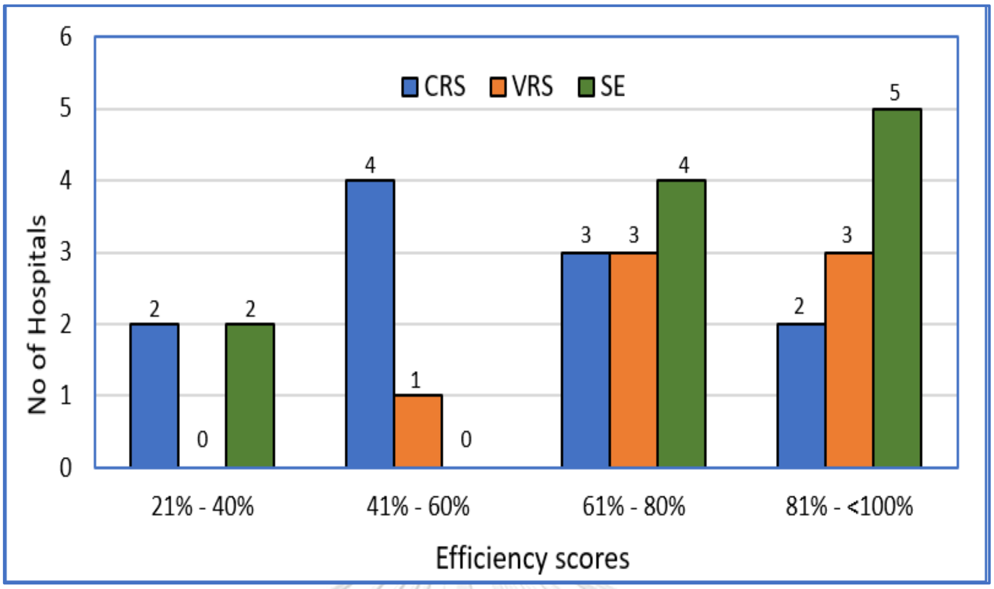
5.3.2.2 Technical Efficiency

According to the results of the study (refer to table 5.3), 9 (45%) of the 20 hospitals were technically efficient, implying that they were efficient (both pure technical and scale efficiency). A percentage change in inputs is accompanied by the same percentage change in outputs. The remaining 11 (55%) were relatively inefficient, having technical efficiency scores less than 100%. The CRSTE score results showed a wide variation between efficient and inefficient hospitals, with a minimum of 24% to a maximum of 100%. The mean overall technical efficiency score is 0.79 (79%) with a standard deviation of 0.25 (25%)

Figure 5.2 showed the distribution of the CRSTE, VRSTE, and SE scores of the inefficient hospitals. The distribution of CRSTE was done as follows; 2 hospitals had technical efficiency scores between 21% - 40%, 4 hospitals had technical efficiency scores between 41% - 60%, 3 hospitals had technical efficiency Scores between 61% - 80%, and 2 hospitals had technical efficiency scores between 81% - <100%. Out of the inefficient hospitals, Kerema and Laloki had the lowest technical efficiency scores of 0.24 (24%) and 0.38 (38%) respectively. Both fall in the efficiency distribution between 21% - 40%.

The average CRSTE score of the inefficient hospitals was 0.61 (61%) with a standard deviation of 0.2 (20%). This means that the inefficient hospitals could improve their outputs by (100-61) 39%. In other words, inefficient hospitals should have augmented all the outputs by 39% to be efficient.

Figure 5. 2 Distribution of CRSTE, PTE & SE of the inefficient hospitals



5.3.2.3 Pure Technical Efficiency

Under VRS approach (refer to table 5.3), out of 20 hospitals, 13 (65%) hospitals (Kerema, Laloki, Angau, Nonga, Buka, Daru, Goroka, Kimbe, Lrengau, Mt Hagen, Popondetta, PMGH, and Vanimo) were technically efficient, scoring 100%, and the remaining 7 (35%) hospitals (Kavieng, Wabag, Mendi, Alotau, Kundiawa, Madang, and Boram) were VRS technically inefficient scoring less than 100%. The VRS technical efficiency scores had the gap between efficient and inefficient hospitals with a minimum score of score 0.60 (60%) to a maximum of 1 (100%). The average score of the overall VRSTE was 0.92 (92%), with a standard deviation of 0.13 (13%). That means the mean score under the VRS approach was better than that of the CRS approach. The hospitals had performed well under the VRS approach.

The distribution of VRSTE scores of the 7 inefficient hospitals was done as follows (refer to fig.5.2); among the inefficient hospitals, 1 hospital (Kavieng) had a technical efficiency score between 41% - 60%, 3 hospitals (Wabag, Mendi & Alotau) had technical efficiency scores between 61% - 80% and 3 hospitals (Kundiawa, Madang & Boram) had technical efficiency scores between 81% - <100%. The inefficient hospitals had an average technical efficient score of 0.76 (76%) and a standard deviation of 0.12 (12%). This implied that on average, they could augment their output by (100-76) 24% at the given level of inputs used to be efficient.

Surprisingly, (refer to table 5.3) 4 hospitals (Kerema, Laloki, Angau, and Nonga) were inefficient under the CRS assumption but were efficient under the VRS assumption. The gap observed between the CRS and the VRS frontiers of these 4 hospitals is due to a problem of scales. Among these 4 hospitals, Kerema and Loloki had the highest level of scales). However, those other inefficient hospitals that were not either on the CRS and VRS frontier had not only scale problems but also due to poor management of the hospitals. They could eliminate the inefficiency attributable to poor management and scale to be efficient.

5.3.2.4 Scale Efficiency

The scale efficiency model deals with inefficiency related to the size of the hospitals. Thus, we may ask how large or how small are they compared to their respective levels of output. These questions are answered by calculating scale efficiency scores for each of these hospitals using DEA. It is important to note that the scale effect is separated by using a VRS data envelopment analysis model. Variable returns to scale can be in two (2) two dimensions; increasing and decreasing returns to scale as discussed in the previous chapters.

Under scale efficiency assumptions (refer to fig 5.2), 9 (45%) were scale efficient while 11 (55%) were scale inefficient. The distribution of scale efficiency scores of the 11 inefficient hospitals were presented as follows; 2 hospitals (Kerema and Laloki) had scale efficiency scores between 21% - 40%; 4 hospitals (Alotau, Kundiawa, Angau, and Boram) had scale efficiency score between (61%-80%) and remaining 5 hospitals (Mendi, Wabag, Nonga, Kavieng and Madang) had scale efficiency score between 81% -<100%. The average scale efficiency score of the inefficient hospitals was 0.74 (74%) with a standard deviation of 0.24 (24%). This implied that on average, the scale inefficient hospitals could adjust their size to maximize their output by (100-74) 26%. Kerema, Laloki, Angau, and Nonga Hospitals with the constant return to scale technically inefficient will be fully attributed to scale efficiencies.

Interestingly, the study identified that 9 (45%) hospitals were efficient in both CRS and VRS which implied that if they increase the inputs, their output in terms of inpatient discharge and outpatient visits will increase in the same proportion. That means the CRSTE hospitals (Buka, Daru, Goroka, Kimbe, Lorengau, Mt Hagen, Popondetta, Port Moresby, and Vanimo) were operating at their most productive scale sizes.

Furthermore, four hospitals (Angau, Kerema, Laloki, and Nonga) are inefficient under the CRS assumption but were efficient under the VRS assumption. This implied that their inefficiencies had resulted from the existence of the scale problem. At the same time, the rest of the inefficient hospitals in both assumptions (CRS and VRS) resulted from both scale and poor management of the hospitals.

The analysis further identified that (refer to table 5.3) 2 inefficient hospitals (Kerema and Laloki) exhibits an IRS. This implied that these two hospitals had not yet reached their optimal sizes. Their output in terms of inpatient discharge and outpatient visits would increase by a greater proportion compared to any increase in health service inputs. They need to increase their sizes and that has to be done practically by internal growth.

On the other hand, the remaining nine (9) inefficient hospitals (Angau, Nonga, Kavieng, Wabag, Mendi, Alotau, Kundiawa, Madang, and Boram) are operating under DRS. This implied that their output in terms of inpatient discharges and outpatient visits would increase by a smaller proportion compared to an increase in health services inputs. These hospitals need to reduce their sizes to achieve an optimal scale.

After analyzing the efficiencies of the hospitals using each of the models, it was identified that the efficiency results were different in CRS or VRS model. However, within each model, the frontier had not been affected by an input or an output orientation. In other words, the firms that were efficient in an input-oriented model are also efficient in output orientation. It was also identified that efficiency values under the CRS model were the same in both (input or output) orientations. But there was a slight difference in values when the VRS model was assumed.

5.3.3 Technical and Scale Efficiency by Region

Table 5.5 shows the distribution of 20 Hospitals in PNG by region. Highlands and Islands Region has 5 hospitals each, Momase Region has 4 and the Southern region has the remaining 6 hospitals.

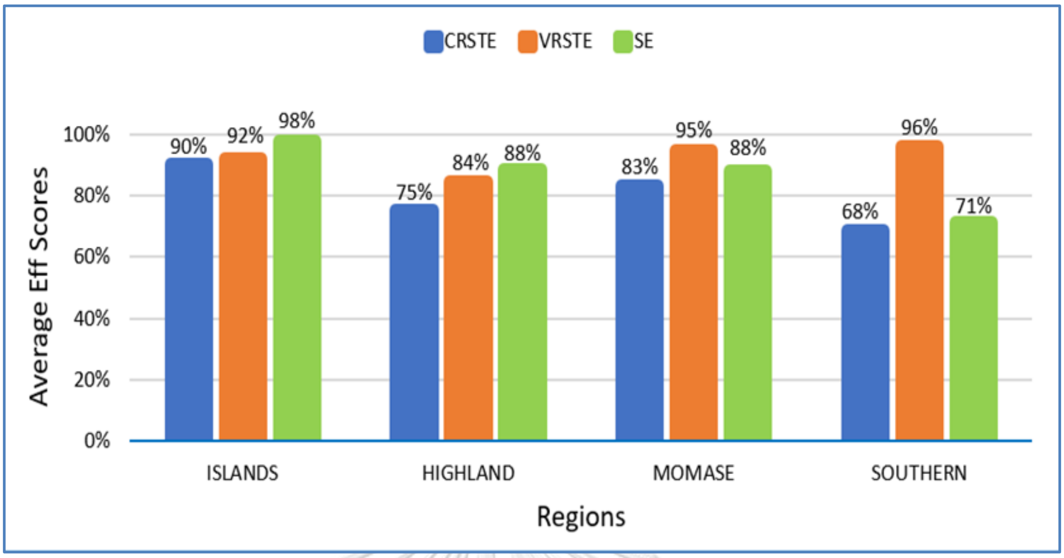
Table 5. 5 Distribution of hospital by the four regions in PNG

NO	HIGHLANDS REGION	ISLAND REGIONS	MOMASE REGION	SOUTHERN REGION
1	MENDI HOSPITAL	BUKA HOSPITAL	VANIMO HOSPITAL	LALOKI HOSPITAL
2	KUNDIAWA HOSPITAL	NONGA BASE HOSPITAL	MADANG HOSPITAL	ALOTAU HOSPITAL
3	WABAG HOPITAL	KAVIENG HOSPITAL	BORAM HOSPITAL	PORT MORESBY GENERAL HOSPITAL
4	MOUNT HAGEN HOSPITAL	LORENGAU HOSPITAL	ANGAU BASE HOSPITAL	KEREMA HOSPITAL
5	GOROKA BASE HOSPITAL	KIMBE HOSPITAL		DARU HOSPITAL
6				POPONDETTA HOSPITAL

To better understand the results, it was possible to visualize the efficiency score of the integrated hospitals by region and make comparisons. Figure 5.3 shows the distribution of CRSTE, VRSTE, and SE scores by region. Based on the results, it was identified that under the CRS model, all the regions had average technical efficiency scores between 68%-90%. Island Region performs well in the CRS model with the maximum average score of 90% while Southern Region performed poorly with the minimum average score of 68%. Highland and Momase Regions had average technical efficiency scores of 75% and 83% respectively.

Furthermore, under VRS, the minimum average technical efficiency scores start from Highlands Regions with 84% to the maximum of 96% with the Southern Region. In this case, the Southern Region performed extremely well from poor performance under the CRS model to the VRS model. Islands and Momase Regions had average technical efficiency scores of 92% and 95%, respectively. So generally, on average, the hospitals performed and achieved the optimal level of operation under the VRS approach. They all had scored at average above 90%.

Figure 5. 3 Distribution of Average TE and SE scores by regions



Under scale efficiency, the average scale efficiency had varied from a minimum of 71% with Southern Region to a maximum of 98% with Island Region. Highlands and Momase Regions had a uniform average scale efficiency score of 88%. Island Region did well in CRS, Southern Region did well in VRS and again Islands Region did well in scale efficiency.

In summary, Islands Region exceptionally well in all the efficiency model (CRETE, VRSTE, and SE). In other words, the Island Region had all three types of efficiency scores (CRSTE, VRSTE, and SE) between 90% to 100% while comparing with the other 3 regions. The level of technical, pure technical, and scale efficiencies was high because of the high utilization of hospitals in the region. On the other hand, the Highlands Region had done very poorly and this result had prompted for other further necessary investigations to establish the relative quality of services provided by those hospitals. Some other contextual or environmental factors that are common in the regions may have a significant impact on the hospital's output level.

5.3.4 Scope for output increases/input reductions to improve efficiency

DEA calculates the efficiency score of a hospital of interest (target hospital) by comparing it with its efficient reference set. The efficiency reference set represents the outputs and corresponding weights of the efficient reference set hospitals which yields a hypothetical hospital (composite hospital) that produces output as much or more than the hospital of interest but also use fewer inputs. The weighted quantity of outputs and inputs are derived by multiplying the DEA-generated weights of its reference set hospitals with its corresponding actual quantities of output and inputs of the reference set hospitals. The difference between the inputs and outputs of the composite hospital and the targeted hospitals provides the input or output required to make the target hospital efficient.

For example, table 5.6 shows the reference set hospitals for the inefficient hospital (hospital of interest). DEA revealed Kavieng Hospital to be relatively inefficient, scoring 0.602 in terms of pure technical efficiency. Kavieng Hospital's inefficiency was identified and measured by comparing it with its efficiency reference set hospitals. The reference set hospitals for Kavieng are Kimbe, Lorengau, and Popodetta. It also shows the weighted quantity of inputs and outputs of the composite hospital. As shown in Table 5.6, the weights of the reference set hospitals are as follows; 0.704 (Popondetta), 0.090 (Kimbe), and 0.206 (Lorengau). The weights are then multiplied with their corresponding actual quantity of output and inputs for each of the reference set hospitals to get a weighted quantity of inputs and outputs for the composite hospital. The composite hospital's targeted (projected) outputs and inputs are attained by summing the weighted output and inputs calculated from each of the reference set hospitals respectively. So, the projected inputs and outputs of the composite hospital is given as (inpatient discharge = 3,559, output visits = 47, 096) and (beds = 126, doctors = 10, Nurse = 51, other workers = 36).

The projected outputs and inputs of the composite hospital are then compared against the actual quantities of inputs and outputs of the targeted inefficient hospital (Kavieng). The difference between the projected output and inputs of the composite hospital and the actual quantity of outputs and inputs of Kavieng Hospital are the output increase and the input reductions that are required for the inefficient hospital (Kavieng) to be efficient.

Hence the Kavieng Hospital can increase the inpatient discharge and outpatient visits by 91% (1,699.89) and 66% (18,722.56) respectively to be more efficient. Alternatively, Kavieng Hospital can also reduce doctors and nurses by (8) 47% and (48) 49% respectively to be efficient while maintaining its current level of beds and other staff.

Table 5. 6 Comparison of Kavieng Hospital with its efficiency reference set hospitals

Efficiency Reference Set Hospital	OUTPUT		INPUT			
	IP Discharge	OP Visits	Beds	Doctors	Nurses	Other Staffs
KIMBE HOSPITAL [A]	$5274^{a} \times 0.09^{w}$ = 474.66	$71318^{a} \times 0.09^{w}$ = 6418.62	$271^{a} \times 0.09^{w}$ = 24.39	$10^{a} \times 0.09^{w}$ = 0.9	$139^{a} \times 0.09^{w}$ = 12.51	$38^{a} \times 0.09^{w}$ = 3.42
LORENGAU HOSPITAL [B]	$2071^{a} \times 0.206^{w}$ = 426.63	$37253^{a} \times 0.206^{w}$ = 7674.12	$107^{a} \times 0.206^{w}$ = 22.04	$8^{a} \times 0.206^{w}$ = 1.65	$59^{a} \times 0.206^{w}$ = 12.154	$18^{a} \times 0.206^{w}$ = 3.71
POPONDETTA HOSPITAL [C]	$3775^{a} \times 0.704^{w}$ = 2657.6	$46879^{a} \times 0.74^{w}$ = 33002.82	$113^{a} \times 0.704^{w}$ = 79.55	$10^{a} \times 0.704^{w}$ = 7.04	$37^{a} \times 0.704^{w}$ = 26.048	$41^{a} \times 0.704^{w}$ = 28.87
COMPOSITE HOSPITAL [D = A+B+C]	3558.89	47095.56	125.98	9.59	50.712	35.99
KAVIENG HOSPITAL [E]	1859	28373	126	18	99	36
Output Increase/Input Reduction [F=D-E]	1699.89	18722.56	-0.016	-8.41	-48.29	-0.008
% Change [G= (F/E)*100]	91%	66%	0%	-47%	-49%	0%
Note: superscript ‘a’ = Actual output and input quantities; superscript ‘w’ = Lambda weights from DEA						

Table 5.7 shows the input reductions and/or output increases that are required to make the seven (7) variable returns to scale technically inefficient hospitals to become more efficient.

Table 5. 7: Input reductions and /or Output increases for the inefficient hospitals

N0	Hospital	Tech Eff	Input/Output	Actual Qty	Target Qty	Difference	%
1	ALOTAU HOSPITAL	0.744	Beds (I)	202	202.00	0	0%
			Doctors (I)	23	11.76	-11.24	-48.89%
			Nurses (I)	231	177.59	-53.41	-23.12%
			Other Staffs (I)	144	77.64	-66.36	-46.08%
			IP Discharge (O)	3,826	5,142.94	1,316.94	34.42%
			OP Visits (O)	49,016	65,887.70	16,871.70	34.42%
2	BORAM HOSPITAL	0.928	Beds (I)	291	258.78	-32.22	-11.07%
			Doctors (I)	23	23	0	0%
			Nurses (I)	121	121	0	0%
			Other Staffs (I)	62	49.47	-12.53	-20.21%
			IP Discharge (O)	6,440	6,942.82	502.82	7.81%
			OP Visits (O)	42,332	45,637.17	3,305.17	7.81%
3	KAVIENG HOSPITAL	0.602	Beds (I)	126	126	0	0%
			Doctors (I)	18	9.59	-8.41	-46.73%
			Nurses (I)	99	50.71	-48.29	-48.77%
			Other Staffs (I)	36	36	0	0%
			IP Discharge (O)	1,859	3,559.63	1,700.63	91.48%
			OP Visits (O)	28,373	47,101.15	18,728.15	66.01%
4	KUNDIAWA HOSPITAL	0.854	Beds (I)	232	232	0	0%
			Doctors (I)	38	11.78	-26.22	-68.99%
			Nurses (I)	226	220.56	-5.44	-2.41%
			Other Staffs (I)	130	72.66	-57.34	-44.11%
			IP Discharge (O)	5,466	6,397.69	931.69	17.05%
			OP Visits (O)	52,606	61,572.79	8,966.79	17.05%
5	MADANG HOSPITAL	0.858	Beds (I)	294	274.98	-19.02	-6.47%
			Doctors (I)	24	22.39	-1.61	-6.70%
			Nurses (I)	213	179.92	-33.08	-15.53%
			Other Staffs (I)	30	30.00	0	0%
			IP Discharge (O)	7,519	8,766.06	1,247.06	16.59%
			OP Visits (O)	37,443	43,653.11	6,210.11	16.59%
6	MENDI HOSPITAL	0.689	Beds (I)	425	157.05	-267.95	-63.05%
			Doctors (I)	14	13.38	-0.62	-4.44%
			Nurses (I)	61	61.00	0	0%
			Other Staffs (I)	85	43.75	-41.25	-48.53%
			IP Discharge (O)	3,159	4,583.94	1,424.94	45.11%
			OP Visits (O)	32,868	47,693.87	14,825.87	45.11%
7	WABAG HOPITAL	0.67	Beds (I)	109	109	0	0%
			Doctors (I)	20	13.13	-6.87	-34.37%
			Nurses (I)	135	128.76	-6.25	-4.63%
			Other Staffs (I)	112	103.69	-8.31	-7.42%
			IP Discharge (O)	2,519	3,758.50	1,239.50	49.21%
			OP Visits (O)	40,950	61,099.93	20,149.93	49.21%

Table 5. 8 Overall output increase or input reduction that is needed for the 7 inefficient hospitals to become more efficient.

	Total Outputs		Total Inputs			
	Outpatient Visits	Inpatient Discharge	Beds	Doctors	Nurses	Other staffs
Quantity	89,058	8,364	1,679	160	1,086	599
%	31%	27%	-19%	-34%	-13%	-31%

For these 7 inefficient hospitals to become relatively efficient, the overall group needs to increase their outpatient visits by 89, 058 (31%), and inpatient discharges by 8, 364 (27%).

At the individual level, Alotau Hospital need to increase its outpatient visits and inpatient discharges by about 34%; Boram Hospital ought to increase its outpatient visits and inpatient discharges by 8%; Kavieng Hospital increases its outpatient visits and inpatient discharges by 66% and 91% respectively; Kundiawa and Madang Hospital needed to have increased its outpatient visits and inpatient discharges by 17%; Mendi Hospital should have increased its outpatient visits and inpatient discharges by 45% and finally Wabag Hospital should have increased its outpatient visits and inpatient discharges by 49%. Given the results, Kavieng Hospitals should have utilized more outputs if the inputs were utilized sufficiently or at the given level.

Alternatively, inefficient hospitals should have saved some inputs in the productions. Most of the inputs are not utilized properly to achieve the optimal output level. As shown in table 5.6, the 7 hospitals that were variable returns to scale technically inefficient could also have improved their relative efficiency by reducing their overall inputs by 1,679 (19%) beds, 160 (34%) doctors, 1,086 (13%) nurses and 599 (31%) other staffs.

By individual hospitals can reduce inputs as follows; Alotau Hospital can reduce the number of doctors by 49%, nurses by 23%, and other staff by 46% while maintaining the given level of beds. Boram hospital can reduce the quantities of beds by 11% and other staff by 20% while keeping the doctors and nurses at the given quantity level. Kavieng Hospital can reduce the number of doctors and nurses by 47% and 49% respectively while maintaining the current level of beds and other staff. Kundiawa Hospital can reduce the number of doctors by 69%, nurses by 2%, and other staff by 44% while maintaining the given level of beds. Madang Hospital can reduce the number of beds by 6%, doctors by 7%, and nurses by 17% while maintaining the current level of other staff. Mendi Hospital can reduce 63%, doctors by 4%, and other staff by 49% while maintaining the given level of nurses. Finally, Wabag Hospital can reduce doctors, nurses, and other staff by 34%, 7%, and 5% respectively.

However, one could ask the policy question of what could be done with the access inputs in PNG in 2017? Papua New Guinea's health sector is facing a series of major challenges including an aging workforce crisis at the front-line health service delivery that must be dealt with if it hopes to deliver better health care. A recent study made by (World Bank 2011) revealed that the sector's shortcomings are manifesting themselves in a worrying health picture in terms of maternal and infant mortality and other traditional communicable diseases. Currently, the shortage of doctors, nurses, and other health personnel is an issue, especially in primary health services.

The access inputs (doctors, nurses, and other support staff, etc.) can be redistributed and transferred to primary health care facilities (level 1- 4) to manage this workforce crisis and other necessary resource gaps.

5.4 Results from the Tobit Regression Model

This section presents the results and discussions from the second stage of the analysis using a Tobit or censored regression model. From the first DEA analysis using the output-oriented VRS model, there are 7 hospitals operated outside of the efficient frontier, meaning they scored efficiency scores less than 100%. Thus, the Tobit regression model is used to predict and identify other contextual factors that might affect the efficiency of these hospitals. The selected Tobit model below was used to explain the observed hospital inefficiencies. This model was earlier presented in the hypothesis section of the paper.

$$Ineff = \alpha + \beta_1 ALS - \beta_2 BOR + \beta_3 RoBTN - \beta_4 RoOPTD - \beta_5 BED + \varepsilon i$$

The model contained the following variable; Inefficiency scores (Ineff) as the dependent variable and average length of stay (ALS), bed occupancy rate (BOR), the ratio of bed to nurses (RoBTN), the ratio of outpatient to doctors (RoOPTD) and hospital size (BED) as the independent variable. Table 5.9 presents a summary of the descriptive statistics (observations, mean, standard deviation, minimum, and maximum) for each of the variables used in the Tobit regression model.

Table 5. 9 Descriptive Statistics (observation, mean, standard dev, min, and max.

Variable	Observarion	Mean	Std. Dev.	Minimum	Maximum
InEff	20	0.12	0.20	-	0.66
ALoS	20	54.95	119.26	4.35	512.87
BOR	20	1,666.70	1,063.88	97.00	3,163.00
RoBTN	20	1.59	1.48	0.07	6.97
RoOPTD	20	3,052.96	2,430.51	466.11	9,235.20
BED	20	238.75	245.95	9.00	1,096.00

The value of the dependent variable censored from below is 0 and censoring from the top is 0.6611296. The mean value is 12%, with a standard deviation of 20%. Table 5.10 presents the Tobit regression model results. The joint null hypothesis; H_0: **$\beta 1=\beta 2=\beta 3=\beta 4=\beta 4=0$** is rejected at the 10% percent level of significance (**Prob χ^2<0.1**) (Refer to Appendix B (1). Therefore, we can conclude that the regression coefficients for the explanatory variables in our model are not equal to zero. It implied that our model as a whole fits significantly better than an empty model (i.e., a model with no predictors).

Table 5. 10 Results from Tobit Regression Model

Variable	Coefficient	t-ratio	p>|t|
ALoS	-0.0037408	-1.58	0.136
BOR	0.0001127	1.56	0.139
RoBTN	0.1928846	2.96	0.01
RoOPTD	-0.0002339	-2.17	0.047
BED	-0.002794	-2.36	0.032
_cons	0.7453091	1.66	0.117
Observations Summary			
Number of observations			20
LR Chi2 (5)			21.05
Prob > Chi2			0.0008
Log likelihood			-1.081256
Pseudo R2			0.9068

In the table, we see that the coefficient for ALoS has a negative sign which is not consistent with the prior expectation, and statistically insignificant. The coefficient for BOR has a positive sign which is also not consistent with the prior expectation and again its insignificant.

The coefficient of RoBTN has a positive sign and is consistent with the prior expectation and statistically significant at a 5% level of significance. In other words, the coefficient for RoBTN is significant because its associated t- value is greater than 0 and the p-value is less than 0.05 (p-value<0.05). A unit increase in the ratio of bed to nurses (RoBTN) would lead to an increase in hospital expected inefficiency score by 0.1929, holding all other variables in the model constant. The higher a hospital's RoBTN, the higher the predicted inefficiency scores would be. This is true because the increase in the beds will increase the RoBTN and that will adversely affect the hospital's efficiency. From the available number of beds, the hospital must have additional nurses to attend to patients per bed effectively to minimize the inefficiency.

The coefficient for RoBTD has a negative sign and is consistent with the prior expectation and is statistically significant as well given its associated p-value is less than 0.05 (p-value <0.05). This implied that a 1-unit increase in RoBTD will decrease the hospital inefficiency scores by 0.0002339 all other factors remain constant. The inefficiency could be minimized by reducing the available doctors for the hospitals having low performance. This could happen because many doctors don't want to be at rural facilities. Hospitals become their choice of postings and this is becoming a norm in the PNG health system.

Similarly, the coefficient for hospital size (BED) also has negative signs consistent with prior expectation and it's also significant at a 5% level of confidence. This means that hospital size is a significant factor in explaining hospital inefficiency. The results indicated that the predicted inefficiency score for big hospitals is 0.002794 points lower than for small hospitals all other factors in the model remain constant. This suggested that even though the coefficients are not significant but from the result, it could conclude that small hospitals are less efficient than big hospitals. The stata generated results are attached as ***Appendix B (2).***

CHAPTER VI: CONCLUSIONS & LIMITATIONS

6.1 Conclusion

One of the goals of the National Health Plan (NHP 2011-2020) is to enhance the efficiency, equity, and quality of the health service in PNG. That means the performance of the health service providers is vital for providing effective and efficient health care to every citizen of the nation. Hospitals are the major organizations in the health system that consumes a larger share of the health resources and ensure the NHP is implemented. It is thus, imperative that hospitals' efficiency in the provision of health services need to be measured to understand the performance of the facilities.

The findings from the first-stage analysis indicated that 7 (35%) of the hospitals were operating at technical efficiency levels well below the efficient frontier. Other similar studies made by Kirigia et al, (2002) which identified 26% of hospitals were technically inefficient and 29.6% of the hospitals were scale inefficient, Kirigia & Asbu (2013) also identified that 68% of the hospitals were VRS technically efficient and 42 % were scale efficient. Another study made by Mujasi et al. (2016) revealed 47% of the hospitals were efficient while 18% were scale efficient. Therefore, even if there is no study conducted in PNG, the available evidence in the other middle-income countries suggested that the magnitude of inefficiency does vary from country to country. All these inefficiencies have been confirmed by the t-distribution test that there are inefficiencies that exist in PNG hospitals.

The study also revealed that more hospitals did relatively poor, meaning their efficiency scores were below 100%. The empirical evidence from the study suggested that sampled hospitals need to have input and output changes required to make the inefficient hospitals relatively efficient. In other words, significant amounts of inputs were under-utilized. The findings also provided that the ratio of beds to nurses is the main driver of efficiency among the hospitals. Since the inefficiency scores are positively correlated with the bed to nurse's ratio, it concludes that the available number of beds needs additional nurses to reduce the inefficiencies of the hospital.

Other findings related to hospital beds suggested that more beds need to be provided to those hospitals with a smaller number of beds. The ratio of outpatient to doctors also suggested that available doctors need to be reduced and that will increase the outpatient to doctor's ratio and have a subsequent reduction in the inefficiency.

Apart from the findings of this study, other related issues that affect health service delivery in PNG is to do with deteriorating road links. The cost of transport is very high and many subsistence farmers can't afford to travel to towns and cities for medical treatments. Residents of some especially in the isolated areas may incur additional costs in travel expenditure. This impedes the movement of people from accessing hospital services and thus delayed treatments at the hospitals. This could be minimized by establishing an effective referral system from primary care units linked to the respective provincial hospitals. People seeking better health services from their provinces to other provinces could be another reason for inefficiencies. Further work is however required to investigate these environmental factors to know why there are variations inefficiencies in the hospital performances.

However, policymakers need to get insight into mechanisms promoting hospital services utilization. They need to develop appropriate strategies to support hospitals with low efficiency to improve their service and thereby better address the problem of under-utilization of health inputs. Information on medical equipment, specialized doctors, and other necessary resources requirements at the hospitals is necessary for policymakers to make effective policy and planning decisions.

6.2 Limitations

The study has several limitations which are mostly related to the availability of the data. Firstly, the key area of limitation is that the facilities included in the study are all provincial hospitals and four referral hospitals. It is however possible that there were differences in the severity of inpatient cases treated in each hospital. The cases can be common or severe depending on the nature of the illnesses. The cases with the common disease have fewer days of admission than the severity. On the other hand, chronic and more severe cases need a longer length of stay and more resource consumption. These groups of patients require more resources including specialist doctors, sophisticated equipment, drugs, and regular attendance and care. The hospitals treating a large number of severe cases, for example, may handle fewer cases and adversely affect aggregate output level, and will thus appear to be relatively inefficient. This data was not available in the PNG National Information System (NHIS). Adjusting for case-mix in the analysis would have helped address this problem and also provide better justification for reductions in input resources or output increases proposed for the hospitals identified by this study.

Secondly, the limitation is distinguished by the unavailability of the various categories of data for health workers (doctors, nurses, clinical officers, laboratory technicians, and anesthetic officers) were all lumped together as medical staff due to the absence of a detailed breakdown of staff categories for all the sampled hospitals. Within the same health workforce category, the quality of labor input may vary depending on individual health worker skills, motivation, and professional experiences. In this case, calculations are necessarily performed by excluding these unavailable data, which is likely to generate different estimates of model parameters and prevent the determination of more accurate estimates and lead to different DEA efficiency scores.

Thirdly, allocative and economic efficiency are perceived as complements to the analysis of technical efficiency. The estimation of allocative efficiency requires data on quantities of health service outputs, health system inputs, and input prices. Nevertheless, the measurement of allocative and economic efficiency is not permitted due to the lack of data on input prices and appropriate panel data limitations. Hence, the study only focused predominantly on technical efficiency and scale efficiency. It is important to note that this study does not attempt to address allocative efficiency and productivity because it was difficult to get accurate input prices and appropriate panel data.

Finally, hospital data does not include specific data that should lead to a deeper understanding of hospital performance. Therefore, results do not provide clear and specific directions that enable the decision-makers and managers in hospitals to implement better policies and planning in terms of wasteful resource reduction or increase output level in terms of patient discharge and outpatient visits.

6.3 Recommendations and future Studies

This section presents the recommendations for the policymakers and the possible studies required due to issues related to considerable data needs. The first stage results demonstrate the variations in efficiency scores of the hospitals. The second stage explains the impacts of contextual factors on the inefficiency scores. The following points should address some recommendations for the decision and policymakers on performance improvements.

Firstly, there is a wide variation in the efficiency scores among the hospitals. The study revealed that 35% of the hospitals in PNG are below the frontier of the pattern of scale efficiency. The study also revealed a significant amount of input resources have been underutilized. They should have been utilized for greater productivity. The policymakers need critical and careful analysis that can enable them to make proper decisions and policies. According to the World Bank report (World Bank, 2011) PNG having a health workforce crisis especially in the rural primary health services. These access inputs can be redistributed to the lower facilities in need to breeze the resources gap for better health care. Hospitals can have more sophisticated management methods for improving hospitals that can help reduce the wasteful utilization of inputs.

Further work is however required to support hospital managers inputting the results to use in enhancing efficiency. Hospitals identified as efficient and inefficient should be investigated further to determine how and why production processes are operating differently at these hospitals. Due to data limitations, some appropriate contextual and environmental factors are not investigated in this study. Among these inputs is the quality of staff (nurses, doctors, and specialists) such as their qualifications and experience including other environmental and contextual factors such as population density, income level, etc. Generally, future studies need a large sample size inclusive of many necessary input data used in the process of obtaining better results.

In the second analysis, the ratio of beds to nurses was the main driver of the inefficiencies. In other words, the total number of beds per nurse attending to in the hospital was positively correlated to inefficiency. It is recommended that from the available number of beds; the hospitals must have additional nurses to attend to patients per bed effectively to minimize the inefficiency. Policymakers can recommend more nursing positions created and recruited into the government system, especially for those inefficient hospitals. As part of the long-term plans, more nursing colleges can be established to train more personnel. PNG is currently having a health workforce crisis due to the aging workforce in the health system. This can provide solutions to efficiency problems.

The findings also indicated that the available doctors allocated to the outpatient services could reduce the performance of the hospitals. Policymakers can have strong management guidelines and policies for hospital managers to allocate doctors within the hospitals. The results and findings from the current study can be used as the guide for managing the allocations of doctors where necessary within the hospitals.

Finally, it was also identified from the results that small hospitals are less efficient than big hospitals. The level of hospitals in PNG is categorized into the level of facilities by the number of doctors, the number of beds, and other standard requirements (National Department of Health (PNG), 2011). Hospitals with fewer beds need beds in proportion to that of the reference set hospitals as benchmarking. This can be used as the guide for supplying beds and increase the hospital size and subsequently reduce inefficiency.

6.4 Study Contributions

The main contribution of the current study is that this is the first publication of the research for measuring the efficiency of the hospitals using DEA in PNG. The study used patient-level data to determine the hospital aggregated level data because of data limitations. The inpatient data and outpatient data were summarized as total inpatient discharge and outpatient visits respectively for every public hospital. The approach could be generalized to other DEA applications in health care or another public sector when the main type of aggregated data required for DEA applications are not available.

Moreover, this study also extended the Data Envelopment Analysis with Tobit regression model as introduced by Tobin (1958) to determine other contextual factors; the average length of stay, bed occupancy ratio, the ratio of bed to nurses, the ratio of outpatient to doctors and number of beds (to denote the size of the hospitals) that have an impact on the technical efficiencies of the hospitals.

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Appendix A

Author (s)	DMUs	Models	Inputs	Outputs
Ali et al. (2017)	12 private and public hospital in Eastern Ethiopia.	Comparative analysis with DEA CCR & BCC model Tobit model	total health staff, cost of drug supply, and capital input proxied by total beds *Independent variables:* Size (beds), BOR, Teachstat, Teaching status, Docstaff, Opinpdays	outpatient department visit, inpatient days, and number of surgeries *Dependent variable:* inefficient scores
Jarjue et al. (2015)	41 Health Centres Gambia	Output-Oriented DEA BCC model.	average of skilled and unskilled labors, beds	inpatient discharge and outpatient visits
Kirigia et al. (2002)	54 Public Hospitals in Kenya	Both DEA CCR and BCC Model	Drs, clinical officers, nurse admin staff, technicians, drugs, foods, beds.	OPD casual visit, special care visit, dental care visit, IP.
Kirigia & Asbu. (2013)	20 public hospitals in Eritrea	Output oriented DEA BCC model Tobit model	doctors, nurses, laboratory technicians & beds *Independent Variable:* OPDIPD, Popn, ALO, region	inpatient days & outpatient visits *Dependent Variables:* Inefficiency scores

Zere et al. (2006)	30 public hospitals in Namibia	Input oriented DEA CCR Model	physician, nurse and administrative staff & hospital beds	outpatient visits and inpatient days
Osei et al. (2005)	17 district hospitals and 17 health centers in Ghana	DEA BCC Model Input Orientation for hospital Output orientation for health centers	Clinical staffs, bed and cost, exp of drug supply.	IP, antenatal care, deliveries, children immunized, family planning visit.
Akazili et al. (2008)	622 Health centres in Ghana	Input Oriented DEA BCC model	Clinical staffs, bed and cost, exp of drug supply.	IP, antenatal care, deliveries, children immunised, family planning visit.
Awara & Susan, 2019	25,000 health centres, 3275 secondary care hospitals and 66 tertiary hospitals in Nigeria.	Input oriented DEA BCC model Tobit Model	beds, doctors, nurses and other staff and beds *Independent variable:* size and ownership	OP, IP surgeries, laboratory tests and scan *Dependent variable:* In efficiency scores

Sultan & Crispim. (2018)	11 Palestinian public hospitals	DEA BCC & CCR model. Tobit Model	beds, doctors, health staffs and administrative staffs Independent variable: BOR. OP-IP Ratio, ALS, Admin-Health staff ratio, hospital location (dummy).	inpatient days, outpatient visits & emergency care *Dependent variable:* Inefficiency scores from CCR model
Ahmed et al. (2019)	62 District Hospitals in Bangladesh	Input-oriented DEA CCR & BCC Model Tobit Model	beds, doctors, nurses *Independent variable:* popln size, poverty head count, BOR, ALS, Bed-Drs Ratio & Bed-Nurse Ratio.	IP & OP and hospital *Dependent variables:* Inefficiency scores
Mujasi et al. (2016)	18 hospitals in Uganda	Output oriented DEA BCC model Tobit	medical staff, hospital beds and budget *Independent variable:* BOR, OPDIPD, ALOS, SIZE, OWN, DIST and POP	OPD visits, IPD, deliveries, major operations and immunizations *Dependent variables:* Inefficiency score

Appendix B (1)

InEff	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
ALoS	-.0037408	.002373	-1.58	0.136	-.0087988	.0013172
BOR	.0001127	.0000722	1.56	0.139	-.0000412	.0002666
RoBTN	.1928846	.0651242	2.96	0.010	.0540757	.3316935
RoOPTD	-.0002339	.000108	-2.17	0.047	-.000464	-3.80e-06
BED	-.002794	.0011844	-2.36	0.032	-.0053185	-.0002694
_cons	.7453091	.448685	1.66	0.117	-.2110403	1.701659
/sigma	.1872119	.0535484			.0730762	.3013477

```
            13  left-censored observations at InEff <= 0
             7     uncensored observations
             0 right-censored observations

. test ALoS = BOR = RoBTN = RoOPTD = BED = 0

 ( 1)  [model]ALoS - [model]BOR = 0
 ( 2)  [model]ALoS - [model]RoBTN = 0
 ( 3)  [model]ALoS - [model]RoOPTD = 0
 ( 4)  [model]ALoS - [model]BED = 0
 ( 5)  [model]ALoS = 0

       F(  5,    15) =    2.82
            Prob > F =    0.0546
```

Appendix B (2)

```
. tobit  InEff ALoS BOR RoBTN RoOPTD BED, ll(0) ul(1)

Tobit regression                                Number of obs     =         20
                                                LR chi2(5)        =      21.05
                                                Prob > chi2       =     0.0008
Log likelihood = -1.0812562                     Pseudo R2         =     0.9068
```

InEff	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
ALoS	-.0037408	.002373	-1.58	0.136	-.0087988	.0013172
BOR	.0001127	.0000722	1.56	0.139	-.0000412	.0002666
RoBTN	.1928846	.0651242	2.96	0.010	.0540757	.3316935
RoOPTD	-.0002339	.000108	-2.17	0.047	-.000464	-3.80e-06
BED	-.002794	.0011844	-2.36	0.032	-.0053185	-.0002694
_cons	.7453091	.448685	1.66	0.117	-.2110403	1.701659
/sigma	.1872119	.0535484			.0730762	.3013477

```
           13  left-censored observations at InEff <= 0
            7     uncensored observations
            0 right-censored observations
```

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