Estimating the cost and technical Efficiency of Norwegian hospitals: An application of stochastic frontier analysis

Bismark Dwommor Antwi

Thesis submitted as a part of the Master of Philosophy Degree in Health Economics, Policy and Management

UNIVERSITY OF OSLO

November 2017

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Department of Health Management and Health Economics (HELED)
Institute of Health and Society
University of Oslo

Supervisor: Sverre A. C. Kittelsen

November 2017

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Bismak Dwommor Antwi

http://www.duo.uio.no/

Printed: Reprosentralen, University of Oslo

Dedication

To Mrs. Antwi, the Badu family and the Dwommor family

Acknowledgement

I am grateful to many people in completing this master’s thesis. First I would like to express my sincere gratitude to my supervisor Professor (II) Sverre A. C. Kittelsen for his advice and guidance as well as providing an office space for me to work on this master’s thesis. Your co-operation and support has been so immeasurable throughout this academic exercise. I must admit it was a privilege having you as my supervisor.

Second I would also like to thank the entire academic and non-academic staff of the Department of Health Management and Health Economics for their kind and cordial relationship during my time at the department. The friendly academic and social environment you created at the department was a big inspiration for me in completing this master programme. My appreciation also goes to the Department of Health Management and Health Economics for the financial assistance in printing this master’s thesis.

Last I would also like to thank Mrs. Antwi, the Badu family and the Dwommor family for their material and non-material support particularly in this master programme and throughout my education. I love you all.

Bismark Dwommor Antwi

November 2017

Abstract

Background: Despite multiple reforms in the Norwegian health care sector with the aim of cost containment and improving efficiency in the sector, health care expenditure appear to be on the rise. This study seeks to investigate the cost and technical efficiency of Norwegian hospitals as well as the impact of technical and allocative inefficiency on total cost of the hospitals.

Methods: We used stochastic frontier analysis and a 13 year panel data on nineteen hospitals to estimate inefficiency of the hospitals. Based on the assumption of cost minimization behavior of hospitals which allows for the dual estimation of production and cost functions, we decomposed inefficiency into technical and allocative inefficiencies and further estimated the impact of both inefficiencies on total cost. Diagnosis related group scores on patients treatment was used as the output variable whiles Physicians, Nurses/ Supporting Staff and Other inputs and their corresponding prices were used as the input variables.

Results: The observed technical efficiency (inefficiency) of Norwegian hospitals was 88.4 %. (11.6%). The impact of technical inefficiency on total cost was 12.3% whiles the impact of allocative inefficiency on total cost was 0.5%. The observed Total cost efficiency (inefficiency) of the hospitals was 87.1% (12.3%). Observation specific values of allocative inefficiency indicated that 54.3% of all hospitals under-utilized Nurses/SS relative to Physicians whiles 46.7% over utilized Other inputs relative to Physicians.

Conclusion: Our estimates of efficiency (inefficiency) show that Norwegian hospitals are not operating on both the technically efficient health care production frontier and optimal total cost frontier.

Key words: *cost efficiency (inefficiency), technical efficiency (inefficiency), allocative efficiency (inefficiency), stochastic frontier analysis, Norway, hospitals*

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List Acronyms

CAE	Cost of Allocative Inefficiency
CTE	Cost of Technical Inefficiency
DEA	Data Envelopment Analysis
DRG	Diagnosis Related Group
EEA	European Economic Area
EU	European Union
FOCs	Fist Order Conditions
FTE	Full Time Equivalent
GDP	Gross Domestic Product
NOK	Norwegian Kroner
OECD	Organization of Economic Coo-operation and Development
RHA	Regional Health Authority
RTS	Returns To Scale
SFA	Stochastic Frontier Analysis
SS	Supporting Staff
TC	Technical Change
WHO	World Health Organization

1 Introduction

The pursuit of cost containment in the healthcare sector has become an important policy concern to many governments in the world today. Both developed and developing countries alike are devising strategies to minimize cost in the healthcare sector. In particular, the attainment of the three primary health goals: efficiency, quality and accessibility have informed major policy reforms in many countries in the Organization for Economic Co-operation and Development (OECD) and European sub region.

In the past two decades, Norway-a member country of the OECD- in an attempt to achieve high efficiency and quality health care that is accessible to all segments of the population has carried out two major reforms. The first of the reforms was the reimbursement reforms implemented in 1997 with its stated objectives of increasing hospital production and reducing waiting lists. Major changes in health care financing were implemented at the time. Owing to the reforms, the capitation-based block grant reimbursement system was replaced with a new payment system that composed of a block grant and Activity Based Financing (ABF) that further utilizes the concept of Diagnosis Related Groups System (DRG) in its final computation (Biørn, Hagen, Iversen, & Magnussen, 2003; Terje Per Hagen, Veenstra, & Stavem, 2006)

This was followed shortly by the centralization of hospital reforms in 2002 with it main objectives as: cost control, equitable distribution of resources across counties and reducing waiting list (Byrkjeflot, 2005; Terje P Hagen & Kaarbøe, 2006). These reforms became necessary at the time because there was a growing concern among policy makers that the health system could collapse. For instance health care budgets between the period 1995 and 1999 had grown drastically reaching almost twice as much as the rest of the public sector. Though political will might have partly contributed to the rapid increase in cost by allocating more resources to the health care sector, there was a strong perception of poor cost containment measures by decision makers at the hospitals among the general public and the media (Slåttebrekk & Aarseth, 2003; Byrkjeflot, 2005).

1.1 Rationale for the study

However, the post reform period did not witness much improvement. It was argued that two years after the reforms, wages of physicians went up by 17% though activities increased in counties that had reached highest levels of quality. Similarly, it was pointed out in an OECD report on Economic survey that, spending accelerated and per capita expenditure on health in Norway still remained one of the highest in the world (Dagens Medicin, May 8th, 2004 & May 14th, 2004; OECD Report, 2005; Byrkjeflot, 2005). Furthermore, recent statistics according to Statistics Norway (2016) indicates that health care spending is on the rise after remaining relatively stable in the wake of the financial crisis. Health care expenditure to GDP ratio increased marginally from 8.8% in 2012 to 8.9% in 2013 drawing level with the OECD average. Preliminary estimates for 2014 and 2015 also stand at 9.3% and 9.9% respectively which further emphasize the increasing trend of health care expenditures.

Another relevant indicator of healthcare expenditure is the per capita health care expenditure. In 2013, Norway's health care expenditure per capita was US$ 5,852 (53,984 NOK) and ranked the third highest in the world after the United States and Switzerland respectively (OECD, 2015). Furthermore, provisional estimates reported by Statistics Norway (2016) indicate that per capita on health care increased to 56,823 NOK in 2014 and further to 59,942 NOK in 2015. Hence these developments have made it necessary to further look into the level of efficiency in the Norwegian health sector.

1.2 Research objectives

Since healthcare financing in Norway is mainly through taxation, the increasing development of health care expenditure is a major concern to policy makers. According to Statistics Norway (2016), the government of Norway accounts for 85% of the total healthcare expenditure. Given this huge expenditure burden on the state coupled with the pattern of health care expenditure in recent times, the emphasis of this study is therefore:

1. to examine the level of total cost efficiency of Norwegian hospitals and
2. to investigate the technical efficiency of Norwegian hospitals
3. to investigate the inputs allocative efficiency of Norwegian hospitals

4. to investigate the cost implications of technical and allocative efficiency (inefficiency) on Norwegian hospitals

1.3 Research questions

The growing importance of the health care sector have triggered major discussions in many OECD countries especially in regards to rising health care expenditures in the last few decades. This has brought the efficiency of the health care sector under scrutiny. As pointed out earlier, Norway spends a significant proportion of its GDP on health care expenditures due to its deep rooted social welfare orientation. According to the principles of pareto- optimality, efficiency of the health care sector coupled with prudent allocation and use of scarce resources are essential elements required for achieving maximum social welfare (Theodoropoulos, 2010). Owing to the efficiency objective of the Norwegian health care sector and the increasing trend of the health care budget as well as the principles of pareto optimality, we therefore raise the following questions:

1. are Norwegian hospitals operating on the optimal total cost frontier?
2. are Norwegian hospitals operating on the technically efficient production frontier?
3. are Norwegian hospitals allocating their resources in the right proportion?
4. what are the implications of technical and allocative efficiencies (inefficiency) on the total cost of Norwegian hospitals?

1.4 Organization of the study

The study is organized into six chapters. The first chapter gives the introduction of the study. Furthermore, the rationale, objectives and research questions of the study are contained in this chapter. Chapter two discusses the background of the study by giving a brief description of Norway, its economic and health overview as well as the mode of organizing and financing of health care in the country. The theory and methods of the study are discussed in chapter three whiles the results and discussions of the study are presented in chapters four and five respectively. The conclusions and recommendations of the study are presented in chapter six.

2 Background

2.1 Norway in brief

Norway is a small country with a population of a little over five million (Statistics Norway, 2016) and located in the Scandinavian Peninsula in the farthest north of Europe. It shares physical borders with Sweden, Finland and Russia as well as the North Sea and the North Atlantic Ocean. It consists of the mainland, the archipelago of Svalbard and the island of Jan Mayen. The total land area of Norway is 386 958 km^2, which averages 16 persons per km^2 (Ministry of Foreign Affairs, 2012; Ringard et al 2013) and makes Norway one of the most sparsely populated countries in Europe.

Norway is a constitutional democracy and divided into three levels for the purposes of administration. They include the state, 19 counties and 429 municipalities (Ringard et al 2013). Since the discovery and commencement of commercial oil production in the late 1960s, Norway has witnessed steady growth over the past years to emerge as one of the wealthiest countries in the world using per capita as measure of wealth. Norway is one of the countries that belong to the European Economic Area (EEA) though not a member of the European Union (EU). However it maintains close relations with the EU. Similarly, Norway also maintains healthy and close cooperation with its sister Nordic countries (Denmark, Finland and Sweden).

2.2 Economic overview of Norway

Norway's economy since the discovery of oil in commercial quantities in the late 1960s has gone through major transformations making it one of the richest countries in the world on GDP per capita basis (OECD, 2016). The estimated GDP per capita of Norway in terms of current prices and purchasing power parity (PPP) in 2016 was USD 62,075 (OECD, 2017). Since the beginning of summer 2014, the collapse of oil prices on the international market exposed the Norwegian economy. Estimated output growth declined from 1.9% in 2014 to 1.6% in 2015 and further declined to 0.4% in 2016 (Statistics Norway, 2016). This emphasizes how the Norwegian economy is dependent on oil. However, due to a combination of prudent fiscal and monetary policies the economy is expected to follow a gradual upswing in 2017 and the subsequent years to follow. The Norwegian economy is forecasted to grow at a rate of 1.7% in 2017 and 2018 (Statistics Norway, 2016).

2.3 Health overview of Norway

The health system in Norway akin to many EU countries is built on the principle of equal access and delivery of health care services to all citizens irrespective of their social, economic and geographic location (WHO, 2017b). Furthermore, decentralization and free choice of provider are key components of the Norwegian health system. Over the years considerable gains have been achieved in the health of the general population. In 2014, life expectancy in Norway at birth was 82 years compared to 76.8 years (WHO, 2016) in the WHO European sub region. Females however had a higher life expectancy of 84 years compared to their males counterparts who on average lived for 80 years at birth (WHO, 2017c). Crude death rate in Norway as at 2014 stood at 8 persons per 1000 population whiles infant mortality at birth for the same period stood at 2 per 1000 live births. According to (WHO, 2017c), the estimated total number of hospital beds and physicians per 100 000 population in 2014 was reported to be 384 and 443 respectively.

2.4 Organization of health care in Norway

The organization of an effective and efficient health care system in every country is key to the attainment its health goals. According to WHO (2017a) a good health system is one that deliver quality services to all people, when and where they are needed. Though the exact organization may vary from one country to another, the key components necessary for the functioning of an effective health system in all instances is dependent on robust financing system, quality and well-motivated workforce. Other elements essential for a well-functioning health system include reliable information to use in decision making; proper maintenance of facilities as well as logistics to deliver quality medicines and technologies.

In Norway, as a result of the 2002 health care reforms, the configuration of the health care system can be placed under decentralized health system and organized at four main levels. They include the national, regional, municipal and the counties level.

At the national level are the ministry of health and health care services and the house of parliament. The latter is primarily a political decision making body. It is responsible for deliberating on national health policies proposed by the health ministry. It is also responsible for budgetary allocations and further granting its approval for the ministry to proceed with the implementation of its decisions and policies. To ensure that the decisions of parliament in particular, regarding the use of public funds and assets in the health sector are consistent with sound financial principles, the Auditor Generals office is tasked to perform routine audit and supervision for parliament. However the main decision making role relating to matters of health care lies with the ministry. It is mandated to formulate and implement national health care policies, programs and action plans as well as making budgetary allocations to different departments in the sector. To execute its core mandate, the ministry functions by collaborating with a number of key institutions and agencies (Ringard, Sagan, Sperre, & Lindahl, 2013). Among the key institutions and agencies the ministry partner with in the delivery of its functions are the Directorate of Health, the National Board for Health Supervision, the National Institute of Public Health, the Norwegian Medicines Agency, the Norwegian Centre for Health Services etc. A detailed responsibilities of these agencies and institutions is provided (Ringard et al., 2013).

The Ministry of Labour and Welfare Administration (NAV) also plays an important and an indirect role in the organization of the health care system. It is responsible for the administration of welfare benefit schemes related to sickness, disability and maternity under the National Insurance Scheme (Ringard et al., 2013).

At the regional level, there are four (previously five) Regional Health Authorities (RHA) that administer and provide specialists care in Norway. The four RHAs are Northern Norway RHA (Helse Nord), Central Norway RHA (Helse Midt Norge), Western Norway RHA (Helse Vest) and, the South-Eastern Norway RHA (Helse Sør Øst). Following the 2002 reforms, the provision of specialist care services which include somatic and psychiatric care as well as drug and substance related abuses have all been delegated to the RHAs. Furthermore, the RHAs are responsible for providing other specialized services such as ambulance services, emergency call systems, laboratories, in-house pharmacies, radiology and x-ray services.

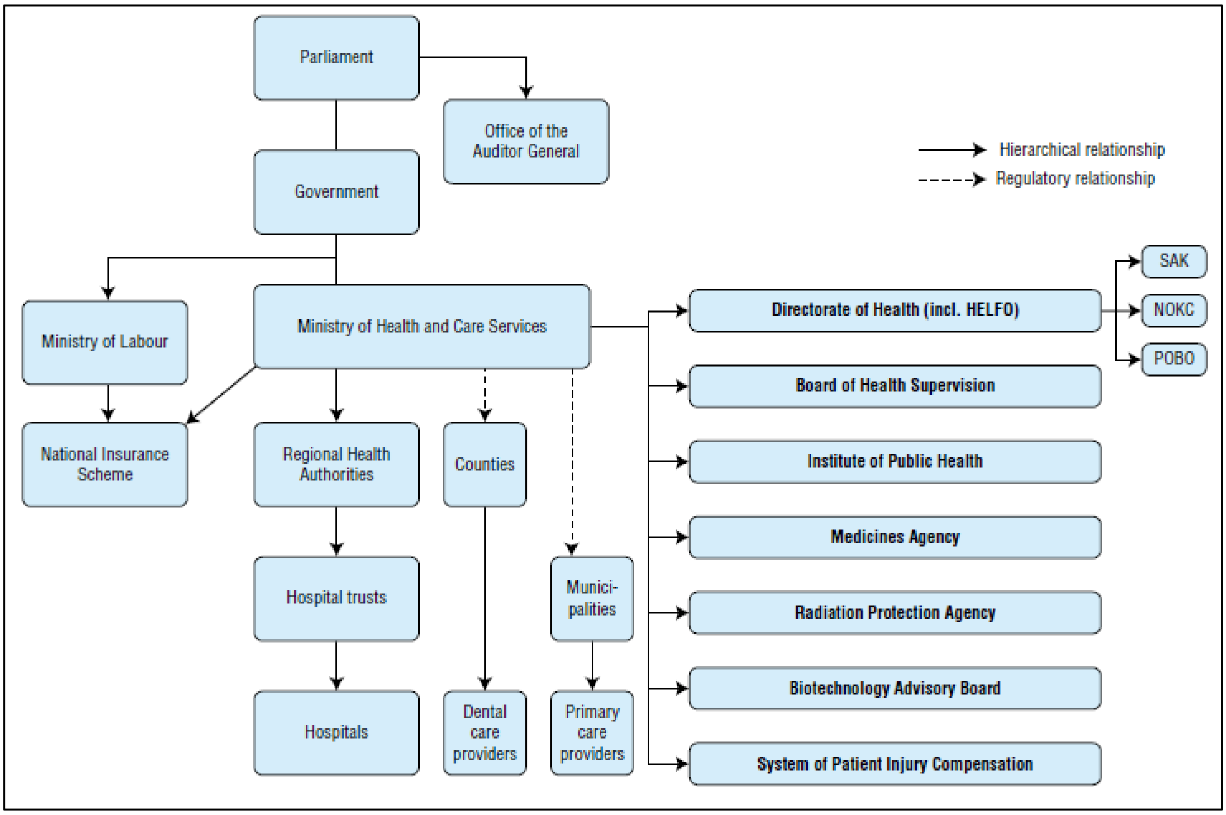
In accordance with the reforms, the state owns all the RHAs and the RHAs in turn owns all the hospitals and are managed under the system of enterprise ownership management. Currently, there are 27 health enterprises that are registered as legal entities with executive boards and governed as public enterprise. Of the 27 health enterprises, there are 21 hospital enterprises, four pharmacy enterprises and an enterprise each for IT and pre-hospital services.

At the municipal level, there are 430 municipalities that are also actively involved in the organization of health care of the population in Norway. The principal functions of the municipalities are stipulated in the Norwegian Primary Health Services Act of 2011. They include the provision of primary health care and its' funding, after-hours care and emergency services, long term care and physiotherapy as well as mental care for all persons within their operational jurisdictions. Furthermore, the control of communicable diseases, preventive medicine, public and environmental health promotion are all under the responsibilities of the municipalities (Helsedirektoratet, 2012).

Besides these three main levels of health care in Norway are the counties. Although the counties are involved in the organization of health care, their roles are somehow limited. They are primarily in charge of the provision of statutory dental care as well as some aspects of general public health care.

To further ensure effective and efficient functioning of the system, several acts and legislations have been enacted to guide the conduct of all stakeholders involved in the health care organization. As discussed in Ringard et al. (2013), these acts and legislations are imperative due to the decentralized nature of the Norwegian health care system. These regulations are supervised by the ministry of health together with its peripheral agencies and organizations. The major acts that regulate the functioning of the system are the Specialist Care Act of 1999 and the Municipal Health Care Act of 2011. The latter regulates the conduct of the municipalities in the organization of primary health care whiles the former guides the RHAs in specialist care organization. Furthermore the Health Services Act of 1993 spells out the modalities for the counties in the provision of dental care. Additionally, the rights of patients that have garnered much attention in recent years, is taken care of by the Patients Right Act of 1999 and the National Insurance Act of 1997. These acts provide the rights of patients and some health benefits they are entitled to particularly during times to sickness, disability or maternity. Figure 2.1 provides a diagrammatic scheme of how the health care system in Norway is organized.

Figure 2.1 Organizational structure of health care in Norway.



Source: (Ringard et al., 2013) [SAK: Norwegian registration authority for health personnel NOKC: Norwegian Knowledge Centre for the Health Services POBO: Health and care services ombudsmen]

2.5 Financing of health care in Norway

Health care in Norway is financed through two main sources. They include public and private sources. The public sources of health care financing are primarily raised through general taxation. This source of health care financing accounted for 85% of the total health care expenditure in 2015 whiles the remaining 15% percent was funded through private sources. The private source is mainly financed through out-of-pocket payment (Statistics Norway, 2016).

In terms of public health care expenditures, taxes are collected by the central government, the counties and the municipalities. Budgetary allocations are then made to the municipalities on a block grant basis under the General Purpose Grant Scheme according to population size, age, gender and other key characteristics. Similarly, the RHAs are allocated funds for hospital care through a combination of 50% block grant and 50% activity based financing (Mossialos, Wenzl, Osborn, & Anderson, 2015).

Private sources of health care funding are mainly covered through out-of-pocket payments and are spent on general practitioner services, transportation and out-patient consultation services. Private for-profit health insurance companies play a limited role in health care funding. Their roles are limited to supplementary functions by offering shorter waiting times to clients for elective services covered under the universal public scheme (Mossialos et al., 2015; Ringard et al., 2013). Only 7% of the total population has private health insurance but 88% of them have their coverage funded by their employers.

2.6 Previous studies

Several studies have been conducted on the performance of Norwegian hospitals in the past with varying estimation techniques and different outcomes. DEA estimation technique has however been applied in most of these studies. In this section, we review some of the literature on efficiency of Norwegian hospitals. The terms productivity and efficiency have sometimes been used interchangeably in the literature though they are two distinct terms, we shall however ignore the distinction between these two terms in this review.

In a study by Terje Per Hagen et al. (2006), they used DEA to analyze the effect of reimbursement on efficiency and quality of somatic hospitals in Norway. Data on cost and quality (measured as patient experiences) was obtained from 213 hospital departments before the Norwegian hospital reforms in 1996 and after the reforms in 1998, 2000 and 2003. DEA was then used to estimate efficiency scores of the hospitals whiles patient satisfaction scores was obtained at the department level from recent patient surveys. They conclude that both technical efficiency and patient satisfaction increased the period after the reforms.

Similarly, Linna, Häkkinen, and Magnussen (2006) studied the cost efficiency of 47 Finish and 51 Norwegian hospitals using discharge data and identical definitions for cost and output measures. In their study they excluded private, military and psychiatric hospitals and applied cost data obtained from the end of year accounts of the included hospitals. Output data consisted of admissions based on DRG system, outpatient visits, day care and inpatient days whiles input data was made up of the net hospital operating costs excluding cost on capital. Cost efficiency was estimated using DEA. In the preliminary findings, they found that Finnish hospitals operated at 17-25% efficiency level higher than Norwegian hospitals; however they explained that, there was wide variation in the cost of the Finnish hospitals.

Furthermore, Kittelsen et al. (2008) investigated whether the Norwegian hospital reforms in 2002 had improved productivity in the hospital sector using DEA. In their study, they included four other Nordic countries as control groups. In total, 728 Nordic hospitals from the period 1999-2004 were studied on comparable productivity measures obtained using DEA. Multiple estimation techniques (DEA, SFA and Bootstrapping) were employed in their final analysis. The results show that hospital reforms in Norway appear to have improved productivity by approximately 4% or more. However, they further indicate that there are minor or contradictory findings in regards to the effects of case mix and activity based financing. For instance, they note that, length of stay is negatively related to productivity.

In a similar study, Linna et al. (2010) examined the cost efficiency of somatic hospitals in the four Nordic countries (Norway, Finland, Sweden and Denmark) by using cross sectional data obtained from the national discharge registries of the respective countries as well as data from the public hospitals. They applied DEA estimation techniques and calculated Farrell efficiency estimates for the year 2002 by using inputs and output data from 184 somatic hospitals. It was observed that, notable differences existed in the average hospital cost efficiency estimates in the Nordic countries. They further note that, Norway and Sweden have lower cost efficiency estimates compared to Finland. Additionally, they also explain that these differences were not as a result of differences in input prices

Furthermore, Anthun, Kittelsen, and Magnussen (2017) in a recent study analyzed productivity growth in the Norwegian hospital sector following the large ownership reform coupled with the subsequent reorganization of the hospital for a period of 16 years from1999 to 2014. They focused on technological change, technical productivity, scale efficiency and the estimated optimal hospital size. In their analysis, bootstrapped DEA was applied and four composite outputs (elective care, emergency inpatient care, day care and outpatient care) were used for the study. In addition, they used fixed-grouper logic to categorized hospital admissions into DRGs. The main findings of the study show that, form 1999 to 2014, mean productivity increased by 24.6% representing on average an increase of 1.5% per year. However, in the period after the reform (2003-2014) average growth per year was 0.5% less compared to the period from 1999-2014. Furthermore, it was observed that the optimal hospital size in majority of the hospitals was smaller than the actual size.

Johannessen, Kittelsen, and Hagen (2017) also assessed physician productivity and the effect of personnel mix on physician productivity owing to the Norwegian hospital reforms in 2002. In their study they defined physician productivity as patient treatments per full-time equivalent (FTE) physician and applied both DEA and a panel data analysis on resource variables compiled from the period 2001 to 2013. The resource variables included FTE and salary costs of physicians, nurses, secretaries, and other personnel. Furthermore, data on patients were measured using the number of patients who received treatment through admission, daycare, out-patient services and diagnosis related group (DRG) scores were used to adjust for variances in patient mix. A number of findings were noted in their study, but key amongst them was that physician productivity decreased over the study period with notable differences in productivity among hospitals. Additionally, though they did not observe any difference in cost efficiency in the DEA results for the study period, they report of a significant decline in allocative efficiency. Furthermore results from the bootstrapped also show that more physicians were used relative to nurses than what was economically optimal.

Kittelsen et al. (2015) investigated productivity differences in the four Nordic countries (Denmark, Finland, Norway and Sweden) by decomposing productivity into technical efficiency, scale efficiency and country-specific possibility sets (technical frontiers) using a pooled set of observations as references. They obtained data on DRG scores on patient discharges and operating cost of all the hospitals in the four countries. They found that minor differences existed in technical and scale efficiency between the four countries whereas wide differences was observed in the production possibilities (frontier position) of the countries. Furthermore, they found that the high productivity level of Finish hospitals was due to the Finish country-specific frontier. In addition they also observed that there was no significant relationship between efficiency and the status of a hospital as a university hospital or located in the capital city.

In all the studies reviewed, only Johannessen et al. (2017), attempts to distinguish between technical efficiency and allocative efficiency of Norwegian hospitals, but uses DEA similar to the rest of the studies. Therefore this study seeks to first, contribute to the existing literature by investigating the cost and technical efficiency of Norwegian hospital using SFA estimation techniques. Furthermore, we attempt to fill the gap in the literature by using SFA estimation techniques to decompose inefficiency in the operations of Norwegian hospitals into its technical and allocative components. In addition we also attempt to examine the implications of technical and allocative inefficiency on the total cost of Norwegian hospitals.

3 Theory and Methods

3.1 Theory

The terms productivity and efficiency have often been used interchangeably in the measurement of the performance of firms in the media in past by different commentators. However there exists a clear distinction between these terms. Productivity of a firm can be defined as the ratio of the output(s) it produces to the input(s) it uses (Coelli, Rao, O'Donnell, & Battese, 2005). On the other hand, efficiency of a firm as explained by Farrell (1957) consist of two main components. They include technical efficiency and allocative efficiency. According to Farrell a firm is technically efficient if it is able to produce maximal output from a given set of inputs whereas allocative efficiency is exhibited by a firm if it is able to use its inputs in optimal proportions with its given input prices and production technology. The product of these two measures of efficiency gives total economic efficiency or cost efficiency.

To measure efficiency it is important for us to have knowledge of the efficient production function to employ. Thus to establish a norm of what the maximal output is. However this is not feasible in a technical sense. Farrell (1957) explains that though the use of the efficient production function sounds plausible in the measurement of the efficiency of a firm, its application faces considerable objection to anything complex such as the hospital and the health care sector. For instance in the healthcare sector it is not possible to determine the efficient production function a hospital should employ due to the complexities of outcomes and inputs used in the process of health care delivery. To overcome this challenge in empirical studies, a sample of hospitals is studied instead. This enables researchers to find which hospital produces the maximum output with its given inputs and technology or uses fewer inputs to produce a given output. Knowledge of the production function of such hospitals in the sample of hospitals provides a benchmark or a frontier to be used in the measurement of the efficiency of the remaining hospitals.

The derivation of the efficient frontier and its illustration shall however not be discussed in this study since it is not our primary objective. Furthermore, this has been widely discussed and treated in the efficiency literature. For details about the derivation and illustration of the efficient frontier see Farrell (1957), Aigner, Lovell, and Schmidt (1977) and Meeusen and van

Den Broeck (1977); Schmidt and Lovell (1979); Coelli et al. (2005), Kumbhakar and Wang (2006) and Kumbhakar, Wang, and Horncastle (2015)

3.1.1 Measurement of efficiency

In efficiency studies, there are broadly two major methods often applied. They are parametric and non-parametric methods. The former applies econometric estimation techniques to estimate a given cost or production function whereas the latter uses the observed data to estimate the frontier without the imposition of any constraints on the functional form (Jacobs, Smith, & Street, 2006).

In the estimation of the non-parametric methods, data envelopment analysis (DEA) is commonly used. This is attributed to the earlier work of Farrell (1957) and subsequently introduced by Charnes, Cooper, and Rhodes (1978). DEA follows a linear programing approach and constructs a piece-wise linear production possibility frontier that literally envelops the production input-output set with the most efficient firms dominating the less efficient ones (Jacobs et al., 2006). DEA unlike most parametric methods has the ability to easily handle multiple input and output production technologies as well as small data sets. However, this is based on the condition that the input and output variables adhere to a reasonable the number of proportional observations (Jacobs et al., 2006; Maniadakis, Kotsopoulos, Prezerakos, & Yfantopoulos, 2009).

The most common form of parametric approach in use today is the stochastic frontier analysis (SFA), which was independently introduced by Aigner et al. (1977) and Meeusen and van Den Broeck (1977). This is based on the traditional approach of regression analysis; however the SFA splits the error component of the production (cost) function into two parts as compared to the conventional regression analysis when estimating the stochastic cost or production function. The two parts are inefficiency which is always negative (positive) in the case of the production (cost) function and the traditional two sided unexplained error term.

The SFA approach was later expanded by Schmidt and Lovell (1979) who proposed that the inefficiency term in the SFA can further be decomposed into *technical* and *allocative* inefficiencies. Thus a firm can be both technically and allocatively inefficient. Schmidt and

Lovell (1979) further explain that technical inefficiency occurs if a firm fails to produce the maximum output from its given inputs bundle which leads to the over use of all inputs. On the other hand allocative inefficiency arises when the marginal revenue product of the input usage of a firm is not proportional to its marginal cost given the input prices. In addition, technically inefficient firms will operate below the optimal production frontier whiles allocative inefficient firms will also operate above the optimal cost frontier. The benefit of expanding the analysis is that, one is able to ascertain information on total economic inefficiency which comprises of technical and allocative inefficiency. We can achieve this by assuming that firms minimize cost subject to their production function in producing their desired output. Based on this assumption we can derive the stochastic input demand frontiers which are in turn used to estimate the stochastic cost frontier. This is achievable because both frontiers (input demand frontier and the stochastic cost frontier) contain input prices and therefore provide useful information on the effect and the cost of total inefficiency as well as technical and allocative inefficiency. However, it is worth noting that based on the estimation of the production frontier alone barring the assumption of cost minimization this would not have been possible since the production frontier contains information only on the use of inputs and the quantity of output produced.

In this study we shall however apply SFA estimation strategy in our analysis of the efficiency of Norwegian hospitals. Our choice of SFA is based on the following reasons. First, SFA has the ability to split the composed error term into inefficiency and statistical noise which permits us to account for random heterogeneity among different hospitals. In contrast, DEA does not split the error term but rather assumes that, inefficiency is the sole explanation of the entire error component. This is a strong assumption and thus makes it very sensitive to outliers and measurement errors. Given that the health care sector is an industry with high degree of uncertainty and measurement errors, there is a greater likelihood that this assumption will be violated. Hence it is imperative to control for firm specific characteristics that impact on the cost or production function. Another advantage of SFA is that, it lends itself more easily to statistical testing techniques. Therefore the statistical significance of all variables that affect the cost or production function of the hospitals can be tested and verified. Thirdly, SFA is less sensitive to the availability of outliers in the data set and firm specific inefficiency can be estimated on the basis of the frontier of the best firms as it is the case in non-parametric studies. Other arguments in favor SFA is that, it allows for the incorporation and measurement of environmental variables which impacts on the performance of hospitals. For instance, the panel data for SFA generalized by Battese and Coelli (1995) and initially developed by Huang and Liu (1994) permits us to measure and test the significance of the effects of environmental variables on mean efficiency scores in one step. Though DEA also allows for the inclusion of such variables, it is prone to small sample bias and lack of comparability of efficiency scores when the effects of different environmental variables are compared between different groups. This is because; DEA measures the effect of environmental variables separately for each subgroup.

In spite of the appeal of the SFA, it has some drawbacks that are worth noting. The main drawback of the use of SFA is the assumptions about the distribution of the composed error term. For instance the random component is assumed to follow a normal distribution with a mean of zero and constant variance (Jacobs et al., 2006). Furthermore, the inefficiency component is similarly assumed to follow half-normal, truncated normal, exponential or gamma distribution (Greene, 2002; Jacobs et al., 2006) but lacks any economic underpinnings for the choice of a specific distribution (Jacobs et al., 2006; Schmidt & Sickles, 1984). Additionally, the two error terms are expected to be independent of one another as well as the regressors of the cost or production function however Kumbhakar and Lovell (2000) pointed out that high linear correlations exist in estimated efficiency rankings with different distributional assumptions. Hence the independence of these components cannot be guaranteed. Another limitation of SFA is the basis of the theoretical foundations of the shape of the stochastic frontier which is derived from economic theory based on the principles of the theory of the firm, however the appropriateness of this theory for efficiency analysis is still debated and yet to be established (Jacobs et al., 2006). Explaining further, Jacobs et al. (2006) point out that existing analytical models of the theory of the firm seek to explain marginal contributions of labor and capital to output which is justified within standard economics. However this is not the primary objective of SFA models which seeks to measure inefficiency scores of individual firms from the unexplained component of the model. Hence the application of statistical test tools designed to examine standard econometric models may not be correct to determine the appropriateness of SFA models.

In the literature it is still debated whether it is appropriate to estimate inefficiency from the input oriented approach (cost function) or an output oriented approach (production function). However preference is given to the input oriented approach in majority of efficiency analysis.

Jacobs et al. (2006) explain that this is due to the convenience in estimating the cost function especially in models with both multiple inputs and multiple outputs. It is also argued that, it is more appropriate to use the cost function as a starting point when estimating technical inefficiency in a cost minimization framework instead of the production because inputs are recognized as endogenous in such cost systems. Though the input oriented approach has widely being used in most studies, it is not without limitations. Kumbhakar and Wang (2006) point out three main challenges associated with the use of the input oriented (cost systems) approach. They include: (1) it is theoretically not possible to link the allocative inefficiency (errors in the cost share equations) with the cost of allocative inefficiency (in the cost function) in a consistent manner since both allocative inefficiency and technical inefficiency contribute to cost increases; (2) there is no proper rationale and explanation for the error components that are routinely included in the cost function and cost share equations before estimation since the noise in the production function may not always be transmitted into the cost function depending on the functional form and (3) estimation of the cost system is quite complex since the components of allocative inefficiency appear in a highly non-linear manner in the cost function and cost share equations.

Furthermore, Kumbhakar and Wang (2006) argue that issues regarding endogeneity of inputs in the output oriented approach can be avoided by framing the model in way that acknowledges inputs as endogenous. In addition they explain that problems of endogeneity of inputs can be avoided by desisting from estimating the production function in a single equation framework. Based on the points raised by Kumbhakar and Wang (2006) and the nature of our data set we shall proceed with the production function in this study.

3.2 Methods

3.2.1 Data

The dataset for this study is a 13-year balanced panel and was first used by Johannessen et al. (2017). It includes 19 hospital trusts in Norway and covers the period 2001 to 2013. Information on each hospital for each year was obtained for all the 13 years under consideration. In the case of hospital mergers owing to the reforms that covered the period under consideration, the pre- and post-reform datum for such hospitals were aggregated and utilized for the new facility in our analysis. Data use on resources and the level of hospital activity were provided by The Norwegian Employers Specter and Statistics Norway. Information on resource use by personnel consisted of remuneration for regular work, overtime payments and payments for on-call services. Additionally, information on the level of activity at the various hospitals was obtained from the Norwegian Patient Register. Data obtained from the patient register included total number of patients treated each year by each hospital for the 13-year period and their corresponding DRG scores. In total we have 247 observations on four variables for 13 years.

The variables are DRG, Physicians, Nurses/SS and Other inputs. The output variable is DRG and this represents the total DRG points scored by each hospital each year for the 13 years under consideration for all cases treated. We have used DRG points instead of the number of patients treated because it provides for similar classification of patients based on DRG codes and points awarded for such treatments. This therefore reduces variation in the activities of the hospitals and their resource use. The input variables are Physicians, Nurses/ Supporting Staff (SS) and Other inputs used by the hospitals in the delivery of health care services. The number of Physicians and Nurses/SS were directly obtained from The Norwegian Employers Specter. The Nurses/SS consisted of professional nurses, assistant nurses, secretaries and non-medical personnel of the hospitals. Other inputs included medical supplies, equipments and other support services used by the hospitals in the provision of health care and were measured in Norwegian Kroner. The national hourly wage rate for Physicians and Nurses/SS personnel were used as estimates to measure the price of each personnel group per annum based on the hours worked each year for the 13 year period. To further estimate the price for Nurses/SS, we aggregated the annual income of all the personnel groups in Nurses/SS and computed the average and used it as the price of Nurses/SS. All prices were measured in Norwegian Kroner. For Other inputs we normalized the price to one (1). For estimation purposes we further normalized all the prices with a million Kroner. To account for technical change over time we also introduced time trend (trend) into our empirical model. This is measured in years.

In the estimation of our results, we used Stata 13 statistical software for statistics and data analysis. Additionally the author-written commands by Kumbhakar et al. (2015) for the estimation of primal models were adopted and installed into Stata for the final analysis of our data.

3.2.2 Estimation strategy

To jointly estimate technical and allocative efficiency, we follow the stochastic frontier analysis independently suggested by Aigner et al. (1977) and Meeusen and van Den Broeck (1977) and later expanded by Schmidt and Lovell (1979). This estimation technique has wide application in efficiency studies in many disciplines including health economics. In this expanded framework proposed by Schmidt and Lovell (1979), we assume that firms are both technically and allocatively inefficient and seek to minimize their cost of production subject to their production function constraint. Starting with the Cobb-Douglas production function, we can proceed to estimate the first-order-conditions (FOCs) of cost minimization by utilizing the theory of cost system for self-dual production functions which yields equivalent outcome whether one starts with the cost or production function. By this system we avoid the estimation challenges encountered when one proceeds with the cost function. We also adapt the Cobb-Douglas functional form since it provides an analytical solution for the derivation of the cost of technical and allocative inefficiency as against the translog functional form which has no analytical solution for the inefficient components. Following the work of Schmidt and Lovell (1979); Kumbhakar and Lovell (2000); Kumbhakar and Wang (2006); Kumbhakar et al. (2015) the Cobb-Douglas production function can be expressed as:

$$\ln Q = \beta_0 + \sum_n \beta_n \ln X_n + v - u \qquad (1)$$

where Q and X are the log of output and inputs respectively. v and u represents the random error and technical inefficiency respectively. β_0 and β_n are parameters to be estimated. The subscript n denotes the nth input and the prefix ln denotes the logarithm. It follows that the corresponding FOCs of cost minimization can be written as:

$$\ln\left({}^{\beta_n}/_{\beta_1}\right) - \ln\left({}^{P_n}/_{P_1}\right) + \ln X_n + \ln X_1 = \xi_n, \qquad n = 2, \dots, N. \qquad (2)$$

Here P_j and P_1 represents the price of the nth and the first inputs respectively. ξ_n also represents allocative inefficiency of the nth and the first inputs respectively. This may take a positive or a negative sign and the sign demonstrates whether the nth input is over-utilized or under-utilized in relation to input 1. The actual value of ξ_n however has no meaning without the accompanying sign.

Following from equations (1) and (2) we can continue to derive the input demand equations which are in turn used to measure the effect of technical and allocative inefficacies. The input demand equations can be specified as:

$$\ln X_1 = B_1 + \frac{1}{r}\sum_{i=1}^{N} \beta_i \ln P_i - \ln P_1 + \frac{1}{r}\ln Q + \frac{1}{r}\sum_{i=2}^{J} \beta_i \xi_i - \frac{1}{r}(v-u) \tag{3}$$

$$\ln X_n = B_n + \frac{1}{r}\sum_{i=1}^{N} \beta_i \ln P_i - \ln P_n + \frac{1}{r}\ln Q + \frac{1}{r}\sum_{i=2}^{N} \beta_i \xi_i - \xi_n - \frac{1}{r}(v-u), \tag{4}$$

$$n = 2, \dots, N$$

Here

$$r = \sum_{i=1}^{N} \beta_i \text{ is a measure of returns to scale and} \tag{5}$$

$$B_n = \ln\beta_n - \frac{1}{r}\left(\beta_0 + \sum_{i=1}^{N} \beta_i \ln\beta_i\right). \tag{6}$$

Before we proceed it is necessary to point out some important features of the input demand equations above. Kumbhakar and Wang (2006) and Kumbhakar et al. (2015) point out that the input demand equations have four parts which we describe here. The first part is the component independent of v, u and ξ and often described as the neoclassical input demand equation. The second part is the component dependent on v that measures stochastic noise and reflected in the equation by the term $-v/r$ which Schmidt and Lovell (1979) referred to as the stochastic input demand equation. The third part is the component dependent on u that measures technical inefficiency and captured in the equation by the term u/r. The fourth part is the component dependent on input allocative inefficiency ξ that indicates whether certain pair of inputs is over-utilized or under-utilized given the sign it carries. This is captured by the term $1/r\sum_{i=2}^{N} a_i\xi_i$ for input X_1 and $1/r\sum_{i=2}^{N} a_i\xi_i - \xi_n$ for input X_n where $n = 2, \dots, N$. Note that that all things being constant the bigger the value of r the smaller the values of these parts $(-v/r\,, u/r\ and\ \xi)$.

Now turning to the subject of technical and allocative inefficiencies and their effect on input demand, we notice two things. First, it can be shown that as a result of input technical inefficiency, demand for each input is increased by $(1/r)\hat{u}$ percent which can easily be obtained by comparing the input demand equation with and without input technical inefficiency(Kumbhakar & Wang, 2006; Kumbhakar et al., 2015). This can be specified as:

$$[\ln X_n|_{u=\hat{u}}] - [\ln X_n|_{u=0}] = \left({}^{1}/_{r}\right)\hat{u} \geq 0 \quad \text{for } n = 2, \dots, N \tag{7}$$

Second, it can also be shown that demand for the inputs X_n and X_1 are either increased or decreased by $1/r\sum_{i=2}^{N}\beta_i\hat{\xi}_i$ percent and $1/r\sum_{i=2}^{N}\beta_i\hat{\xi}_i - \hat{\xi}_n$ percent for input X_n where $n = 2, \dots, N$ respectively. This is the part attributable to input allocative inefficiency and may be positive or negative as earlier noted. This explains the reason why it may increase or decrease the demand for an input. Furthermore, it can also be easily shown by comparing the input demand equation with and without input technical inefficiency (Kumbhakar & Wang, 2006; Kumbhakar et al., 2015). This can be specified as:

$$\left[\ln X_n|_{\xi=\hat{\xi}}\right] - \left[\ln X_n|_{\xi=0}\right] = \frac{1}{r}\sum_{i=2}^{N}\beta_i\hat{\xi}_i - \hat{\xi}_n \text{ for } n = 2, \dots, N \tag{8}$$

Following from equations (3) and (4) and the effect of technical and allocative inefficiency on input demand, we can proceed in a likewise manner to estimate the joint effect of both inefficiencies on total cost. The cost function associated with these systems of equations can be written as:

$$\ln TC = B_0 + \frac{1}{r}\ln Q + \frac{1}{r}\sum_{i=1}^{N}\beta_i \ln P_i - \frac{1}{r}(v-u) + (E - \ln r) \tag{9}$$

Here

$$B_0 = \ln r - \frac{\beta_0}{r} - \frac{1}{r}\left(\sum_i \beta_i \ln\beta_i\right), \qquad \text{and} \tag{10}$$

$$E = \frac{1}{r}\sum_{n=2}^{N}\beta_n\xi_n + \ln\left(\beta_1 + \sum_{n=2}^{N}\beta_n e^{-\xi_n}\right) - \ln r \tag{11}$$

Like the input demand equations (3 and 4), the cost function (9) also has four parts (Kumbhakar & Wang, 2006; Kumbhakar et al., 2015) and shall be necessary for our discussions on the impact of technical and input allocative inefficiency on total cost. Note that all variables are defined as before except $\ln TC$ which represents the log of total cost and E which measures the component of total cost attributable to input allocative inefficiency. The first part of the cost function is the component independent of v, u and ξ (i.e. stochastic noise, technical inefficiency and input allocative inefficiency) and often referred to as the neoclassical cost function. The second part is the component dependent on v represented by the term $-v/r$ which Schmidt and Lovell (1979) referred to as the stochastic cost frontier. The third part is the component dependent on technical inefficiency u and represented by the term u/r . Last the fourth part is the component dependent on allocative inefficiency ξ which is captured by the term $(E - \ln r)$ where $(E - \ln r) \geq 0$. Bearing in mind the above components of the cost function, it can easily be shown that, due to technical inefficiency, total cost increases by $(1/r)u$ percent. This can be estimated by comparing the total cost function with and without technical in efficiency.

$$[\ln TC|_{u=\hat{u}}] - [\ln TC|_{u=0}] = \left({}^{1}/_{r}\right)\hat{u} \geq 0 \qquad (12)$$

In a like manner we can also show that total cost increases by $(E - \ln r)$ percent due to input allocative inefficiency. We can obtain this by comparing the total cost function with and without allocative in efficiency.

$$\left[\ln TC|_{\xi=\hat{\xi}}\right] - \left[\ln TC|_{\xi=0}\right] = (E - \ln r) \geq 0 \qquad (13)$$

Having shown that total cost exceeds the optimal cost (frontier) due to the joint impact of technical inefficiency and allocative inefficiencies, we can continue to estimate this system of equations using maximum likelihood procedure. However some assumptions would have to be made about the error terms. Schmidt and Lovell (1979); Kumbhakar and Wang (2006) and Kumbhakar et al. (2015) achieved this by making the following assumptions which we replicate here in this present study:

$$v \sim N(0, \sigma^2), \qquad (14)$$
$$u \sim N^+(0, \sigma^2), \quad \text{(follow a half normal distribution)} \qquad (15)$$
$$\xi \sim MVN(0, \Sigma), \qquad (16)$$
ξ_n are independent of v and u. (17)

Here we assume that v is a random symmetric variable distributed as $N(0, \sigma^2)$ and it captures the variation in the output owing to factors (natural disasters, measurement errors etc.) which the firm has no explicit control over. Similarly, u is a non-negative variable representing technical inefficiency on the part of the firm. u is distributed as $N^+(0, \sigma^2)$ and follows a half normal distribution. Moreover, for the purposes of estimation we shall also assume normal distribution on input allocative inefficiency (ξ) and furthermore no random noise in allocative inefficiency. The last assumption on the independence of ξ, v and u is for simplicity. As earlier indicated ξ demonstrates over-utilization or under-utilization of the firms inputs according to the sign it carries. Having in mind these assumptions, we can define the joint probability distribution of $v - u$, and ξ as follows:

$$f(v - u, \xi) = g(v - u). h(\xi), \tag{18}$$

where

$$g(v - u) = \frac{2}{\sigma} \phi\left(\frac{(v - u)}{\sigma}\right) \Phi\left(\frac{-(v - u)\sigma_u}{\sigma_v \sigma}\right) \tag{19}$$

Here $\phi(\cdot)$ and $\Phi(\cdot)$ represents the probability distribution function (pdf) and cumulative distribution function (cdf) of the standard normal variables respectively where $\sigma = \sqrt{\sigma_u^2 + \sigma_v^2}$. Similarly $h(\xi)$ defines the multi-variate variable for $h(\xi)$. It follows from the above that the likelihood function for the system of equations in (1) and (2) can be expressed as:

$$L = g(v - u) \cdot h(\xi) \cdot |J| \tag{20}$$

Here also $|J|$ represents the determinant of the Jacobian matrix of the transformation for $v - u$, ξ_2, $\xi_3, \dots, \xi_n$ to $\ln X_1, \ln X_2, \dots, \ln X_n$ which we shall define shortly. The importance of the Jacobin matrix in this framework is due to the treatment of inputs (X) as endogenous variables under the assumptions of cost minimization. The Jacobian can be defined as:

$$|J| = \left|\frac{\partial(v - u,\ \xi_2, \xi_3, \dots, \xi_n}{\partial(\ln X_1, \ln X_2, \dots, \ln X_n)}\right|. \tag{21}$$

Following from the above, we can also derive the logarithm of the likelihood function for each observation which can also be expressed as:

$$\ln L_i = \varphi - \frac{1}{2}\ln\sigma^2 + \ln\phi\left(\frac{(v_i - u_i)}{\sigma}\right) + \ln\Phi\left(-\frac{(v_i - u_i)\sigma_u}{\sigma_v\sigma}\right)$$
$$-\frac{1}{2}\ln|\Sigma| - \frac{1}{2}\xi_i\Sigma^{-1}\xi_i + \ln|J_i| \,. \tag{22}$$

where φ is a constant.

The above log-likelihood function can be estimated using maximum likelihood but can be challenging. Therefore to avoid the challenges in estimating the log-likelihood function we follow the technique used by Schmidt and Lovell (1979); Kumbhakar and Wang (2006) and Kumbhakar et al. (2015). They achieved this by concentrating the likelihood function with respect to Σ. Following this technique the elements of σ_{nk} and Σ can be gotten from the following specifications:

$$\sigma_{nk} = \frac{1}{T}\sum_i \xi_{ni}\xi_{ki}, \qquad n, k = 2, \ldots, N, \tag{23}$$

$$\Sigma = \frac{1}{T}\sum_i \xi_i\xi_i' \tag{24}$$

Taking advantage of the concentrated specification we can substitute equation (24) into the log-likelihood function to obtain the concentrated log-likelihood function. Maximizing the observation sum of the concentrated log-likelihood function gives the parameters of the maximum likelihood estimates. From the estimated parameters and following the examples of Jondrow, Lovell, Materov, and Schmidt (1982); Kumbhakar and Wang (2006) and Kumbhakar et al. (2015), we can proceed to estimate the observation-specific effect of technical inefficiency (u) on output. This can be written as:

$$\mathrm{E}\{u|(v-u)\} = \mu^* + \sigma^*\frac{\phi(\mu^*/\sigma^*)}{\Phi(\mu^*/\sigma^*)}, \tag{25}$$

Here $\mu^* = -(v-u)\,\sigma_u^2/\sigma^2$ and $\sigma^* = \sigma_u\sigma_v/\sigma$.

Similarly, using the residuals from the FOCs, we can also estimate the allocative inefficiency ξ_n for the input pair $(n, 1)$. As earlier noted, the value of ξ_n alone has no meaning without the sign it carries. The sign it carries gives us evidence of over-utilization or under-utilization of the each pair of inputs. For instance, if $\xi_n > 0$, then it implies that the nth input is under-utilized relative to the first input. Therefore, as previously discussed, to ascertain the degree of over-utilization or under-utilization of each pair of inputs in terms of cost, we first estimate the effect of u and ξ on the input demand equation which are in turn used to compute the effect of u and ξ on total cost.

3.2.3 Empirical model

The empirical Cob-Douglass model to be estimated (production) is of the form:

$$\ln Q_{it} = \beta_0 + \sum_n \beta_n \ln X_{nit} + \beta_t t + v_{it} - u_{it} \tag{26}$$

where n = Physicians, Nurses/SS and Other inputs; t represents time trend and β_t is a parameter to be estimated. All other variables are defined as before. The subscripts *i* and *t* have been introduced here to represent the hospital and year respectively to reflect the panel structure of our data set. In the earlier sections we excluded the subscripts *i* and *t* for the sake of notational convenience. Introducing these two elements into the empirical model will not change any of the equations as previously derived but shall only explain the panel set-up of the model. Using Physicians as a numeraire the corresponding FOC is of the same form as in equation (2)

$$\ln\left({}^{\beta_n}/_{\beta_1}\right) - \ln\left({}^{P_{nit}}/_{P_{1it}}\right) + \ln X_{nit} + \ln X_{1it} = \xi_{nit}, \tag{27}$$

Here n = Nurses/SS and Other inputs (Physicians is used as a numeraire)

4 Results

This chapter presents the main results of the study. The first section gives the summary statistics of all the variables used in the study whiles the second section presents the estimated results of the parameters of the production function of the hospitals. Furthermore our main results of interest on the estimated measures of inefficiency are presented in section three.

4.1 Summary statistics

A total of four variables were collected on 19 hospitals for this study. They include one output variable and three input variables with their corresponding prices. The output variable DRG is measured using the Norwegian DRG coding system. The input variables are Physicians, Nurses/SS and Other inputs. Other inputs was measured in Norwegian Kroner and its price was normalized to 1. Physicians and Nurses/SS were measured as the number of personnel and the corresponding prices were measured as personnel income per year. For Nurses/SS the price was computed as the average of all the personnel groups that constitutes Nurses/SS as earlier explained. Table (1) below gives a summary statistics of all the variables used in the study.

Table 4.1 Summary statistics (2001-2013)

Item	**Variables**	**Obn (N/n)**	**Mean**	**Std. Dev.**	**Min.**	**Max.**
Output(Q)						
	DRG	247/19	59611.01	42860.08	11976.24	235416.2
Inputs quanties(X)						
	Physicians	247/19	434.3482	383.5867	76	2035
	Nurses/SS	247/19	2808.674	2263.461	605	11766
	Other inputs	247/19	1181.764	961.1503	213.5336	5033.973
Inputs prices (P*)						
	Physicians	247/19	1.347782	0.1303891	0.9626448	1.818739
	Nurses/SS	247/19	0.6617074	0.0502239	0.4926875	0.7685052
	Other inputs	247/19	1	0	1	1

*****prices are in million kroner

N=Total number of observations; n=number of hospitals

From Table (1) we find that mean DRG (output) score for all the hospitals is 59611 with a deviation of 42860 about the mean. The highest DRG score recorded in the sample in the 13 year period was 235416 and the least DRG score was 11976. The number of Nurses/SS in all the hospitals studied varied from a minimum of 605 personnel to a maximum of 11766. We also note that for the personnel inputs Nurses/SS recorded highest average. The average number of Nurses/SS for all the hospitals was 2809 with a deviation of 2264 for the period. On the other hand the average number of Physicians for the period was 434 with a deviation of 384. The number of Physicians for all the hospitals for the period varied from a minimum of 76 personnel to a maximum of 2035. The application of Other inputs varied from a minimum of 214 million Kroner to a maximum of 5034 million Kroner in the 13 year period. The average application of Other inputs was 1182 million Kroner with a deviation of 961 Kroner. In terms of the personnel input prices, Physicians however recorded highest average price for the period. The reported average price of Physicians for the period is 1.35 million Kroner with a deviation of 0.13 million Kroner. Furthermore the price of Physicians varied from a minimum of 0.96 million kroner to a maximum of 1.82 million Kroner. On the other hand the price of Nurses/SS varied from a low 0.49 million Kroner to a high of 0.77 million Kroner for all the hospitals in the 13 year period. The average price of Nurses/SS for the period for all hospital investigated was 0.66 million Kroner with a deviation of 0.05 million Kroner. Because the price of Other inputs was normalized to 1, we note that the mean price as well as the minimum and maximum prices of all Other inputs used in the period is 1 million Kroner with no deviation.

4.2 Results from the estimated production function

Presented in Table (2) are the estimated results from the empirical production model in equation (25).

Table 4.2 Estimated Cobb-Douglas production function results

Dependent (Output) variable = ln DRG

Variable (In log)	**Coef.**	**Std. Err.**	**P-value**	**95% CI**
Physicians	0.159***	0.003	0.0001	0.15-0.16
Nurses/SS	0.525***	0.008	0.0001	0.51-0.54
Other inputs	0.332***	0.006	0.0001	0.32-0.34
Trend	-0.003	0.002	0.2960	-0.01-0.002
Constant	3.674***	0.110	0.0001	3.45-3.89
$\boldsymbol{\sigma_u^2}$	0.022***	0.007	0.0001	0.01-0.04
$\boldsymbol{\sigma_v^2}$	0.007***	0.002	0.0001	0.004-0.03
Log likelihood	617.412			

*** Significant at 1%

Table (2) presents the estimated coefficients, the p-values and the confidence intervals of the estimated production function. The coefficients of Physicians, Nurses/SS and Other inputs are all in natural logarithms except the trend variable which is in absolute terms. We find that all inputs have positive relationship with the output variable as expected since the carry positive signs. Nurses/SS have the highest coefficient of 0.524 followed by Other inputs with a coefficient of 0.332 and Physicians with the least coefficient of 0.159. Additionally, we notice that all the input variables are significant at 1% level of significance. Further reported in Table (2) are the confidence intervals of the coefficients which are all significant except for the trend variable. The reported log likelihood of the estimated function is 617.4 whiles the reported coefficients for the inefficiency and stochastic noise (σ_u^2 and σ_v^2 **)** are 0.022 and 0.007 respectively. In addition they are all significant at all conventional levels.

4.3 Estimated inefficiencies and other statistics

From the estimated results of the production function, we also computed our primary measures of interest in this study (technical and allocative efficiencies and their impact on total cost) which we report in Table (3) below. Further reported in Table (3) are technical change (TC) and returns to scale (RTS) which are also relevant in the context of efficiency analysis.

Table 4.3 Summary results of estimated technical inefficiency, allocative inefficiency, impact of inefficiencies on cost , TC and RTS

Estimated inefficiencies, TC and RTS			**Impact of inefficiencies on cost**			
	Mean	**Std. Dev.**		**CTE**	**CAE**	**CTE and CAE**
$\hat{\boldsymbol{u}}$	0.116	0.490	mean	0.123	0.005	0.129
$\hat{\xi}_N$	0.001	0.120	25%	0.075	0.001	0.082
$\hat{\xi}_O$	-0.001	0.200	50%	0.102	0.003	0.107
RTS	1.020	n/a	75%	0.162	0.007	0.165
TC	-0.003	n/a				

$\hat{\boldsymbol{u}}$= technical inefficiency

$\hat{\xi}_N, \hat{\xi}_O$ = input allocative inefficiency for Nurses/SS and Other inputs respectively.

CTE, CAE= cost of technical and allocative inefficiencies respectively

From Table (3) we find that the computed mean technical inefficiency ($\hat{\boldsymbol{u}}$) of all the hospitals for the period under study is 11.6% with a deviation of 0.5. Furthermore the estimated mean input allocative inefficiency of Nurses/SS $(\hat{\xi}_N)$ and Other inputs $(\hat{\xi}_O)$ are 0.001 and -0.001 with a deviation of 0.120 and 0.200 respectively. The estimated mean individual impacts of technical and allocative inefficiencies on total cost are 12.3% and 0.5% respectively. The reported mean joint impact of technical and allocative inefficiency on total cost is 12.9%. Additionally the reported joint impact of technical and allocative inefficiencies on total cost at the 25th, 50th and 75th percentiles are 8.2%, 10.7% and 16.5% respectively. Similarly the reported 25th, 50th and 75th percentiles of the impact of technical inefficiency on total cost are 7.5%, 10.2% and 16.2 respectively while that of allocative inefficiency are 0.1%, 0.3% and 0.7% respectively. Other statistics of interest reported in Table 3 are the RTS (1.020) and TC (-0.003).

Before we continue to the discussion of the above results in the next chapter, we also present the histograms of technical inefficiency (Figure 4.1), impact of technical inefficiency on total cost (Figure 4.2), impact of allocative inefficiency on total cost (Figure 4.3) and the joint impact of technical and allocative inefficiency on total cost (Figure 4.4). Note that the scale of the axes varies greatly between the panels in Figure 4.

Figure 4.1

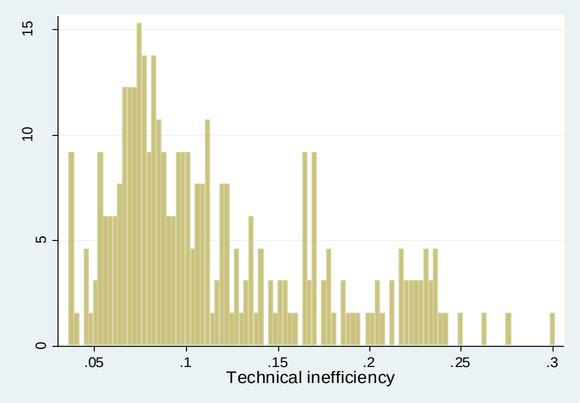


Figure 4.2

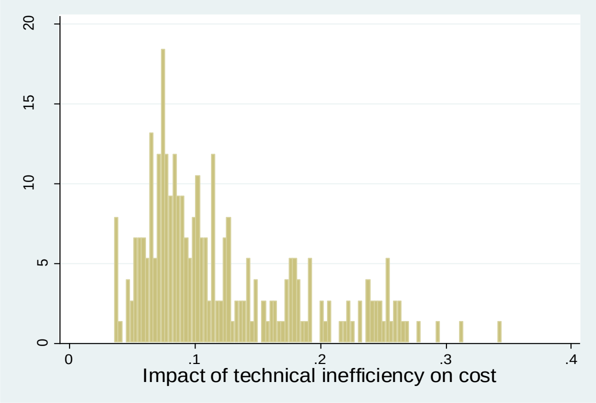


Figure 4.3

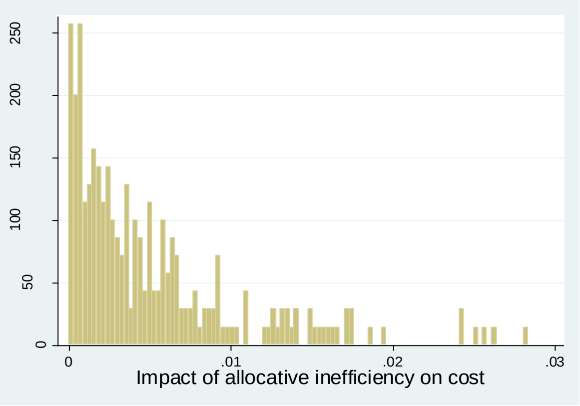
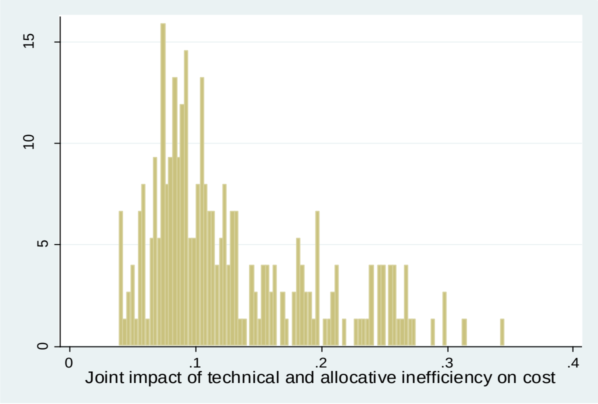


Figure 4.4



5 Discussion

This chapter discusses the main results of this study presented in the previous chapter. The study was conducted using a panel data on Norwegian hospitals with the primary purpose of investigating the cost and technical efficiency of Norwegian hospitals. A total of 247 observations on 19 hospitals across Norway were included in the study from the period 2001 to 2013. To estimate efficiency we followed the expanded SFA suggested by Schmidt and Lovell (1979) that permits the separation of the inefficiency component in the original SFA framework into technical and allocative inefficiencies. The estimation of technical and allocative inefficiency and their impact on total cost in such a framework is achievable under the assumption of cost minimization behavior of hospitals in the production of their desired output levels. This allows for the dual estimation of the production and cost function of the hospitals in a single framework bearing evidence on the technical and allocative inefficiencies in the production process of the hospitals as well as the joint impact of these two components on the total cost of the hospitals. However the error components of such system of equations require some assumptions. Hence, we assumed that the stochastic noise (v) is normally distributed, technical inefficiency (u) is half normally distributed and allocative inefficiency (ξ) is distributed as a multi-variate normal variable and are independent of v and u. This has been extensively discussed in chapter three of this study. The discussion to follow is organized into three parts. The first and second parts focus on the results from the estimated parameters of the production function and the computed measures of inefficiency as well as other statistics of interest in the context of efficiency analysis. The third part of the discussion highlights some the limitations of this study.

5.1 Results of the production function

The results presented in chapter four reveal some interesting findings. First the results from the estimated production function (Table 4.2) show that all inputs (Physician, Nurses/SS and Other inputs) are positively related to the outcome variable (DRG) as was expected. We further note that they are highly significant at the least level of significance. Since these variables are expressed in the natural logarithm, it suggests that on average a percentage increase in the number of Physicians will be followed by a 15.9 percentage increase in DRG points (health care provision or treatment in the hospitals) holding all things constant. Similarly a percentage increase in the use of Nurses/SS and Other inputs on average lead to 52.5 percentage and 33.2 percentage points increase in DRG points (health care provision or treatments in the hospitals) respectively all else being equal. The only surprising result is the coefficient of the trend variable which has a negative sign as against our expectation. This measures the effect of the health care production process in terms of technical change with respect to time (years). Since it carries a negative sign it implies that the hospitals in our sample are technically retrogressing at approximately 0.3% per year. However this is highly insignificant at all conventional levels of significance and hence it is not statistically different from zero. Additionally, we find that the parameters σ_u^2 and σ_v^2 are highly significant with positive coefficients. The parameter σ_u^2 confirms the presence of inefficiency in the production process (health care production process) which is further separated in into technical and allocative inefficiencies as suggested by Schmidt and Lovell (1979) in their expanded analysis of the original SFA framework. This inefficiency is a confirmation that the hospitals are operating below the optimal health care production frontier. Thus they fall short of the optimal health care production frontier by approximately 2.2%. On the other hand the parameter σ_v^2 indicates the presence of stochastic noise in the health care production process. This is attributable to factors beyond the control of the hospitals such as natural disasters, measurement errors which make sense in the context of health care provision.

5.2 Results of estimated inefficiencies, TC and RTS

From our previous discussion it was clear that there was some evidence of inefficiency in the output of our sample under study. However, this information does not bear evidence on how much of this inefficiency is due to technical inefficiency and allocative inefficiency as well as their impact of total cost of the hospitals. This returns us to the objectives of this study and the key questions of interest we raised in the first chapter: (1) are Norwegian hospitals operating on the optimal total cost frontier? (2) are Norwegian hospitals operating on the technically efficient frontier? (3) are Norwegian hospitals allocating their resources in the right proportion? (4) what are the implications of technical and allocative efficiencies (inefficiency) on the total cost of Norwegian hospitals?. The results presented in Table (4.3) provide us some answers and understanding to these questions.

First we note that the mean of the non-negative one sided disturbance technical inefficiency term $(\hat{u})$ is approximately 0.116. This was computed using the formula proposed by Jondrow et al. (1982). It implies that the hospitals in our sample are on average operating below the optimal (technically efficient) health care production frontier by 11.6%. In other words, total output of the hospitals is 11.6% on average below the optimal output level. This implies that the hospitals are operating at 88.4% on average of their technically efficient output level. This estimate of technical efficiency is similar with the 89.7% that was observed by Kittelsen et al. (2015) in their study: Decomposing the productivity differences between hospitals in the Nordic countries. Figure (4.1) in chapter four depicts the histogram of the deviation of the health care production frontier from the optimal (technically efficient) frontier.

Second, on the question of whether the hospitals allocate their resources in the right proportion, we also find a disproportionate use of resources as can be seen from the estimates of the inputs (resource) allocative inefficiency terms (ξ_N and ξ_O). Once again, the values of ξ_N and ξ_O alone do not make sense without their respective signs. Since the input allocative inefficiency estimate for Nurses/SS is positive ($\text{i.e.}\, \xi_N = 0.001 > 0$), it indicates that Nurses/SS are under-utilized relative to Physicians. This further implies that Physicians to Nurses ratio is on average higher than the cost minimizing ratio. This results is also similar to the findings of Johannessen et al. (2017) who observed high use of physicians relative to nurses than what was economically optimal in their study: Assessing physician productivity following the Norwegian hospital reform: a panel and data envelopment analysis.

Similarly we also note that the input allocative inefficiency for Other inputs is negative ($\text{i.e.}\, \xi_O = -0.001 < 0$), indicating that Other inputs are over-utilized relative to Physicians. This indicates that Physicians to Other inputs ratio is on average lower than the cost minimizing ratio. Since the results bears evidence on over-utilization and under-utilization of resources, it implies that the hospitals have not chosen their resource allocation in the right proportions given their input prices and the cost minimizing ratios. Note that this has further implications on the total cost of the hospitals. Furthermore, observation specific values of allocative inefficiency show that 54.3% of the hospitals under-utilized Nurses/SS relative to Physicians whiles 46.7% also over utilized Other inputs relative to Physicians.

As it was shown in section (3.2.2) both technical inefficiency and input allocative inefficiency have cost implications on the total cost function of a firm. Our results further reveal that the mean impact of technical inefficiency (CTE) on total cost of the hospitals is 0.123. This indicates that due to technical inefficiency ($\hat{u}$), the hospitals are operating at 12.3% on average above the optimal total cost frontier (function) or total cost of the hospitals is further increased by 12.3%. The histogram of the deviation of total cost frontier from the optimal total cost frontier is shown in Figure (4.2) in chapter four above. Similarly we find that the mean impact of input allocative inefficiency (CAE) on the total cost of the hospitals is 0.005. Though this is minimal, nonetheless it has implications on the total cost of the hospitals. It suggests that as a result of input allocative inefficiencies $\left(\hat{\xi}_N \text{ and } \hat{\xi}_O\right)$ the total cost of the hospitals is raised by 0.5% on average or the total cost frontier (function) of the hospitals is above the optimal total cost frontier (function) by 0.5% on average. Shown in Figure (4.3) in chapter four is the histogram of the deviation of the total cost frontier from the optimal cost frontier due to input allocative inefficiencies. In addition the reported joint mean impact of technical and input allocative inefficiencies on total cost of the hospitals is 0.129. This shows that due to the combined effect of technical and input allocative inefficiencies $\left(\hat{u}, \hat{\xi}_N \text{ and } \hat{\xi}_O\right)$, total cost of the hospitals is raised be 12.9% on average above the total optimal cost (optimal cost frontier). This translates into approximately 87.1% total cost efficiency on the operations of the hospitals in our sample. The histogram in Figure (4.4) shows the deviation of total cost frontier from the optimal cost frontier due to the joint impact of technical and allocative inefficiencies.

These results may partly explain the increasing cost development in the Norwegian health care sector as well as the growing waiting lists in the hospitals since the hospitals are not operating on their optimal total cost and health care production frontiers. Furthermore these results are consistent with the extended SFA framework proposed by Schmidt and Lovell (1979) that inefficiency can be separated into both technical and allocative inefficiencies where each of them has cost implications on the total cost of a firm. We find from this study that due to technical inefficiency the hospitals in our sample are operating on average 11.6% below their potential capacity whiles at the same time total cost of the hospitals are further raised by 12.9 % on average as a result of the joint impact of technical and allocative inefficiencies. Though our estimate of total cost efficiency varies from most of the estimates reported by Linna et al. (2006) it may be due to the difference in estimation techniques and data. While SFA and panel data are used in this study Linna et al. (2006) used a cross-sectional data and DEA estimation technique.

Besides our main inefficiency estimates of interest, we also computed and reported in Table (3) the mean values of returns to scale (RTS) and technical change (TC) which are also relevant in the context of efficiency analysis. Though not discussed in the methodology section they can easily be obtained from the Cobb-Douglass production as follows: (1) $RTS = \sum_n \beta_n$, in the case of the Cobb-Douglass production function this is a constant and equal to one (i.e. homogenous of degree one) (2) $TC_{it} = \partial \ln Q_{it} / \partial t = \beta_t$. From the results we find that the mean RTS of the hospitals is 1.020 which is approximately equal to one and hence satisfies the constant RTS property of Cobb-Douglass production function. This implies that the hospitals may not necessarily benefit from their size since RTS is approximately equal to one. This is however expected since the Cobb-Douglass production function predicts unitary returns to scale. The mean TC of the hospitals is -0.003 which is quiet surprising and indicates that the hospitals have technically retrogressed over the period as earlier mentioned. Given the Cobb-Douglass production function, this implies that cost of the hospitals have increased on average 0.3% per annum for the period under study. This could be as results of the hospitals operating below their potential capacities or combining their resources in sub-optimal proportions. However this was found to be insignificant and statistically not different from zero.

5.3 Strengths and Limitations of the study

The main strengths of this study include the estimation technique and the use of DRG points as the output variable. First the estimation technique permits us to decompose inefficiency into its technical and allocative components as well as further estimating the impact of both technical and allocative inefficiency on total cost of the hospitals. Having knowledge of both technical and allocative inefficiencies is very important for decision makers to achieve their efficiency objectives. Furthermore the use of DRG points instead of the number of patients treated helps to minimize some of the variation in the activities of the hospitals to a large extent. This is because DRG classifies patients on the basis of similar treatments and resource needs of patients as well as taking into consideration the severity of diseases.

However this study just like any other study is not without some limitations. The main weaknesses of this study include the assumptions imposed on the error structures and the cost minimization behavior of hospital which is debatable. If some of these assumptions are relaxed there is a greater likelihood of obtaining different findings. For instance we assumed that there is no random noise in the measures of allocative inefficiency which could be relaxed. In addition different distributional functions (truncated, exponential, gamma) could be assumed for the non-negative one sided technical inefficiency component which may alter our final estimates of inefficiency.

Furthermore, no mention was made of the existence of exogenous variables which impact on the production or the cost function of the hospitals. Introducing these variables into our analysis may affect our findings and hence the eventual estimates of inefficiencies.

In addition we cannot claim that our data was free of measurement errors. Since measurement errors cannot be avoided in any data we are also mindful this fact. For instance we aggregated data on the number of Nurses/SS and Other inputs which may not be ideal in a perfect world. Furthermore, DRG scores may not reflect all the different case mix despite the fact that it adjusts for severity of diseases. Similarly DRG scores may have been reviewed over the study period pertaining to the economic developments in the economy. Nonetheless, DRG scores are the standard measures used for reimbursements and reporting activities of hospitals in Norway.

Last, no sensitivity analysis was conducted to check the robustness of our findings by running comparable models using different estimation techniques and functional forms. Though some minor changes may occur when different functional forms or estimation techniques are used, however they do not substantially alter the findings.

6 Conclusion and Recommendations

This study investigated the cost and technical efficiency of Norwegian hospitals using the extended SFA framework proposed by Schmidt and Lovell (1979) and a thirteen (13) year panel. The estimation strategy enabled us to decomposed inefficiency into its technical and allocative components as well as estimating the individual and joint impact of technical and allocative inefficiencies on the total cost of Norwegian hospitals.

The results showed that Norwegian hospitals are on average operating at 11.6% below their technically efficient output level. This implies that the hospitals are 88.4% technically efficient. Our measures of allocative inefficiency also revealed that the Norwegian hospitals are not combining their inputs in the optimal proportions relative to their input prices and the cost minimizing ratios. Based on observation specific values, we observed that 54.3% of the hospitals in our sample under-utilized Nurses/SS relative to Physicians whiles 46.7% of the hospitals also over-utilized Other inputs relative to Physicians. We further found that due to technical inefficiency total cost of the hospitals was raised by 12.3% whiles allocative inefficiency also raised total cost of the hospitals by 0.5%. Finally, we observed that the joint impact of technical and input allocative inefficiency raised the total cost of the hospitals by 12.9%. Thus the hospitals are on average operating at 12.9% above their total optimal cost or are 87.1% total cost efficient.

Though the findings of this study are similar to previous studies, we recommend that further studies should be conducted on the efficiency of Norwegian hospitals by taking into consideration some of the limitations of this study. Particularly, future research should focus on the simultaneous application of SFA and DEA techniques with different functional forms (Cobb-Douglass and the translog) to ascertain the robustness of the results and if they are similar to the present study.

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