ERASMUS UNIVERSITEIT ROTTERDAM
ERASMUS SCHOOL OF ECONOMICS

Beyond the Cost-Effectiveness Ratio
The Effect of Medical Technology on Dutch Hospital Performance

MSc Accounting, Auditing and Control

Academic year 2015 - 2016

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Abstract

Background: this study examines the effect of investments in medical technology on hospital performance. Current literature presents mixed evidence on this relation and uses various indicators of both medical technology and hospital performance. Health care expenditures in the Netherlands are very high and increasing. A part is caused by procurement of medical technology. This thesis contributes by creating an extensive theoretical framework and performing both a qualitative and quantitative study.

Methods: this study uses mainly a quantitative method, while case studies complement and explain the regression results. It uses eight different indicators, for three types of hospital performance. These indicators are average length of stay, number of discharges and unfinished DBC's, the number of persons with minimal one finished DBC, profit, solvability, operating costs and the readmission rate. The independent variable is a lagged variable of the investments in both medical devices and information technology. The thesis uses longitudinal data and panel data models, for the years 2011 to 2014.

Results: investments in medical technology directly and positively affect process indicators, it negatively influences financial performance and is insignificant for quality performance. Investments in medical technology also have an indirect association with financial and quality performance. This association is positive for profitability and readmission rates, but negative for solvability and operating costs.

Conclusion: investments in medical technology have a positive influence on nonfinancial performance of Dutch hospitals, but a negative effect on the financial performance. Hospitals should pay more attention to the cost-effectiveness of investments in innovative technologies.

Table of Contents

List of Figures

List of Tables

List of Abbreviations

CE	Cost Effectiveness
CBS	Central Bureau of Statistics
DBC	*Diagnose Behandel Combinatie*: Diagnostic Treatment Combination
DHD	Dutch Hospital Data
GDP	Gross Domestic Product
FTE	Full Time Equivalents
HIT	Health Information Technology
HHI	Herfindahl-Hirschman Index
ICER	Incremental Cost Effectiveness Ratio
IGZ	*Inspectie Gezondheidszorg*: Inspection Health Care
IT	Information Technology
NZA	*Nederlandse Zorgautoriteit*: Dutch authority of health care
NVZ	*Nederlandse Vereniging van Ziekenhuizen*: Dutch association of hospitals
OECD	Organization for Economic Co-operation and Development
WHO	World Health Organization
US	United States (of America)

1. Introduction

Health care expenditures are currently peaking. According to the World Health Organization (WHO), the Dutch governmental health expenditures as percentage of total governmental expenditures increased from 12% in 2002 to 20.7% in 2012 (WHO, 2015). The Organization for Economic Co-operation and Development (OECD) states that the Netherlands ranks second in health expenditures per country, with 11.8% of GDP in 2012. Only the United States (US) spend more on health care as percentage of GDP (OECD, 2014).

New health technologies take a part in causing the increasing health care expenditures. The industry for medical devices accounted for 7.5% of total health care expenditures in Europe in 2012 (Ciani et al., 2016). New medical technology is even seen as one of the major drivers of health care spending (Kowdley and Ashbaker, 2011 & Pomp and Vuijc, 2008). However, the Netherlands is lacking guidelines about maximum prices for medical technologies. Several institutions are appointed to advise the Ministry of Health about the cost-effectiveness of health technologies. However, this advice is not binding and moreover, it concentrates particularly on drugs and not on other health technologies (Franken, Koopmanschap and Steenhoek, 2014).

The majority of the medical technologies is used in hospitals. However, much of the hospital performance literature concentrates on cost efficiency and productivity from the perspective of competition, compensation schemes or hospital ownership (e.g. Bayindir, 2012, Houle et al., 2012, Mutter et al., 2008, Shen et al., 2005 & Schut and van de Ven, 2005). Other studies examine the motivations of hospitals to adopt new medical devices (e.g. Song et al., 2013, Mas and Seinfield, 2008 & Weisbrod, 1991). Hence, the effect of medical technology on hospital performance receives little attention, while more knowledge would be useful to hospitals. For instance, a study that evaluated the cost drivers of hospital costs found that hospital technologies, such as diagnostic radioisotope labs, accounted for 19% of total increasing costs. The study was conducted in the US using cross-sectional data in the period 1998 – 2001 (Hay, 2003).

The studies that focus specifically on the link between medical technology and hospital performance (e.g. Goldstein et al., 2002, Blank and van Hulst, 2008 and Agha, 2013), use different indicators of both hospital performance and medical technology. Often these studies are lacking a solid theoretical framework. The majority of the studies solely examines whether

technology has a direct effect, while the theory also implicates an indirect effect of technology of hospital performance. Therefore this study examines the following research question:

What is the effect of investments in medical technology on the performance of Dutch hospitals?

I expect that the results contribute to multiple parties. First, this study gives a better understanding of the role of medical technologies in hospitals. It attempts on developing a theoretical framework, which can be replicated in future studies. Especially by constructing a model that observes both a direct and an indirect relation complements the current literature. Second, the effect of medical technology on hospital performance is of importance to many stakeholders. The mission of a hospital is to serve the public benefit (Merchant and van der Stede, 2012). It provides an useful insight which can help in the hospitals' decision making considering technology investments. Through this, it should have potential benefits for patients, medical specialists and other employees. Third, the results are of importance to the Dutch government and institutions evaluating the cost-effectiveness of medical technologies. These parties can take the results into account in their decision whether to create regulation on procurement of medical devices, while aiming on cost reduction of health expenditures.

The research methods consist of both a qualitative and quantitative part. I perform three case studies at different hospitals. The objective of the case studies is to provide an additional insight in the relation between medical technology and hospital performance. For the quantitative analysis I use longitudinal data of Dutch hospitals during 2011 – 2014. Annual investments in both medical devices and IT, is the proxy for hospital technology and hospital performance comprises eight different indicators. The hypotheses assume both a direct and indirect effect of medical technology of several types of hospital performance.
I find that medical technology is direct positively related to process indicators and negatively to financial performance. The direct relation on quality performance is insignificant. However, I do find evidence of an indirect relation between medical technology and quality and financial hospital output, with the hospital process as mediating factor.

The structure of the paper is as follows. Chapter two provides an overview of the existing theories on hospital behavior, providing the foundation for the theoretical premises in this thesis. Chapter three continues with empirical evidence. The fourth chapter contains the hypothesis

development, while chapter five elaborates on the methodology and data. Chapter six and seven present the results of the case studies and regression analysis respectively. Finally, chapter eight concludes the research with a conclusion and discussion.

2. Literature Overview

Chapter two contains an overview of the relevant theoretical concepts that determine the relation between medical technology and hospital performance. Section 2.1 discusses the theories on hospital behavior and performance, while paragraph 2.2 explains the theoretical link between medical technology and hospital performance. Section 2.3 continues with developing a theoretical framework discussing confounding factors. I present a conceptual model in paragraph 2.4 while concluding the chapter.

2.1 Theoretical Concepts

This section discusses the theoretical concepts found in the academic literature about hospital behavior. There exist two main streams of literature that explain why hospitals function differently than firms in other industries than health care. These are the agency theory and the economic theory of non-profit firms.

Agency Theory

The agency theory says that a relationship contains both a principal and an agent. Both are assumed to be motivated by self-interest, minimize their effort and maximize their utility. In every relation exists uncertainty to some extent, because future outcomes caused by agents' actions cannot be perfectly predicted. This is called the agency problem. The principal can incur costs to obtain information about the agents' motives, but it is assumed that perfect information is too expensive as the cost exceeds the benefit. Therefore, principals inevitable have less information about their agents' actions, which is called information asymmetry. This information asymmetry has two consequences: adverse selection and moral hazard. Adverse selection arises as principals are unable to completely identify an agents' abilities and intentions before agreeing on a contract. The principal may agree on a contract that the agent cannot satisfy. Moral hazard occurs as the agent acts in its own interest and not in that of the principal because of information asymmetry (Pontes, 1995).

When one applies this theory to a hospital, many principal-agent relationships that include information asymmetry reveal. Examples of these principal & agent relations are hospital management & medical specialists, patient & medical specialists and health insurance companies & hospital management. Harris (1977) for instance argues that the hospital actually exists of two separate entities, because of the information asymmetry between the medical staff (agent) and hospital administration (principal). The hospital administration comprises all supporting facilities, including the management, which makes decisions considering hospital strategy and facilities. The medical specialists however decide when to use these facilities, after a patient visits the hospital. The interests between the hospital administration and medical staff do not align. Physicians in general feel obliged to do anything in their power to improve a patients' wellbeing, regardless of costs. However, the hospital administration aims to let a hospital perform at its best, both in non-financial and financial terms. The problem of moral hazard occurs, as the agent serves his own interest and not that of the principal, which is possible because of information asymmetry (Harris, 1977).

Principal-agent relationships occur in many situations, across different industries. However, some differences between health care and other industries exist. First, the product that a hospital provides, health care, is something that is not easy to evaluate. Many products that a person buys contain a degree of information uncertainty, but normally a person can learn from experience whether he or she appreciates the product. However in the event that a patient uses health care, the product is mainly advice from a physician, and it is uncertain how useful this advice is to a patient. Most people do not use health care regularly, but episodic, which limits their ability to evaluate services further. Moreover, usually a state of health is very specific to a certain situation. Therefore, user experience is often not the solution to the uncertainty problem (Arrow, 1963). The same applies to the relation between the hospital management and medical specialists. The hospital management is less able to learn from experience than in other industries, as the services that the medical specialists provide are often unique and not based on a routine.
Second, an important characteristic of the health care industry is the existence of a third-party payer which is not the patient itself. The insurance system in the Netherlands guarantees reimbursement for patients above the amount of the deductible. This leads to moral hazard, with patients that do not have an incentive to contain the costs of their treatment. Moreover, physicians

control a large amount of health care expenditures while health insurance companies or hospitals bear the costs (Harris, 1977).

Theory of nonprofit firms

The second theory that distinguishes health care from other industries, is that hospitals have a different type of ownership than most organizations. In general, Dutch hospitals are private nonprofit institutions. This means that the people who control the hospital are not entitled to the hospitals' earnings, like in for-profit firms. Hence, the main difference lies in the importance of the amount of profit at for-profit firms versus the distribution of profit in nonprofit firms. The major defining characteristic of a nonprofit firm is the organization's purpose. In the case of a hospital, this purpose is serving the public benefit (Merchant and van der Stede, 2012).

As the mission of a hospital is to serve public benefit, hospital performance consists of both financial and nonfinancial performance indicators. Especially nonfinancial performance indicators are important to hospitals (Goldstein et al., 2002). Many not-for-profit organizations experience difficulty in defining a clear goal. As their purpose is not solely maximizing monetary benefits, but serving the public benefit, their goals involve multiple stakeholders. Considering a hospital, the interests of the management, physicians, third-party payers, patients and the government are conflicting. However, as hospitals serve the public benefit their performance should be according to the goals of all these constituents. This requires clarity and certain tradeoffs among goals, though with uncertainty about these tradeoffs it is difficult to assess the performance of a hospital. Moreover, even in the event of goal clarity, it is hard to define a quantitative bottom-line performance indicator. The extent to which a hospital has achieved every financial and nonfinancial target, cannot be measured by one accurate indicator (Merchant and van der Stede, 2012).

Normally, efficient ownership leads to a minimization of the contracting costs and monitoring costs. Because hospitals are not-for-profit organizations, they will not fully exploit their market power to a patient who experiences a severe health shock. Hypothetically, if a health care provider can invest in both improving quality and reducing costs, the for-profit provider has a stronger incentive to invest in both than the not-for-profit provider has. However, the for-profit incentive to contain costs is often too strong as it neglects the adverse effects of quality reduction. Hence, the larger the adverse effects of cost reduction on a decrease in quality, the more

nonprofit institutions arise (Sloan, 2000). This reasoning implies that most hospitals do not produce at the marginal cost, like for-profit firms intend to do. A hospital has a budget constraint, but it will not solely produce profitable products because quality also has an important place in its utility function. Furthermore, the hospital may produce less efficient because patients have a health insurance. There is no incentive to produce at the minimum cost possible because consumers do not pay their own bill (Newhouse, 1970). I already explained that the latter argumentation is also a result of information asymmetry.

Hospital Performance

Because it is difficult to assess hospital performance by a single indicator, both hospitals and external evaluators use multiple indicators. In academics, hospital performance evaluation concentrates on "providing quality care at a reasonable cost" (Li and Collier, 2000). This definition lacks a description of what quality is and what a hospital should produce in order to perform well, although it broadly covers two aspects. First, a hospital should provide proper services, which means that the production output matters. Second, a hospital should be able to offer the services at an attractive price, which requires financial health. Both are output measures. Every firm transforms volumes of input into volumes of output. The hospital uses resources like labor and technology in its process to produce an output. The process through which inputs are transformed is of importance to the value of the output. For instance, a hospital may have a sufficient number of doctors (input) available, but if these doctors do not use an effective communication system, the process will be less efficient. This also has a consequence for the outputs produced by a hospital. This reasoning indicates that an indirect relation exists between input and output, via the process.

However, the value of the input can also directly influence output, for instance when certain inputs generate such cost savings that alter the financial output of a hospital. Or when the inputs contain such a degree of quality that the quality of output increases directly. Output is defined as the number of constant-quality actions or activities (Schreyer, 2012). Regard that output is not equal to outcome. An outcome is a state that is valued by a customer. Examples are a functioning laptop, or a level of knowledge after finishing an education. The fundamental outcome of the health system is health, which includes both length and quality of life (Rosen and Cutler, 2007). A hospital provides health care and patients use these services with the purpose to obtain a better health status. Thus, the ultimate outcome of the hospital is health as well. Therefore one could

argue that hospital performance is determined by the health status of people discharged from the hospital.

However, an outcome like health status is influenced by many factors. Important determinants of personal health are environmental circumstances, personal investments in health like food consumption, safety and exercising and research & development (Rosen and Cutler, 2012). Another determinant of health is the medical care provided in a hospital. In this way, a hospital contributes to a persons' state of health through its own output.

To summarize, an outcome corresponds to the purpose for which goods and services are used and an output corresponds to the goods and services themselves (Schreyer, 2012). The amount of inputs influence hospital performance both directly and indirectly through the process. Indirectly because inputs can improve the productivity and efficiency of the process, which enhances both quality and financial outputs. Directly because some inputs are cheaper, create more revenue or contain a higher qualification that both financial and quality outputs increase, without the need of process improvement. The quality of services in a hospital is associated with the health outcomes of a person. This reasoning is visualized in the following framework.

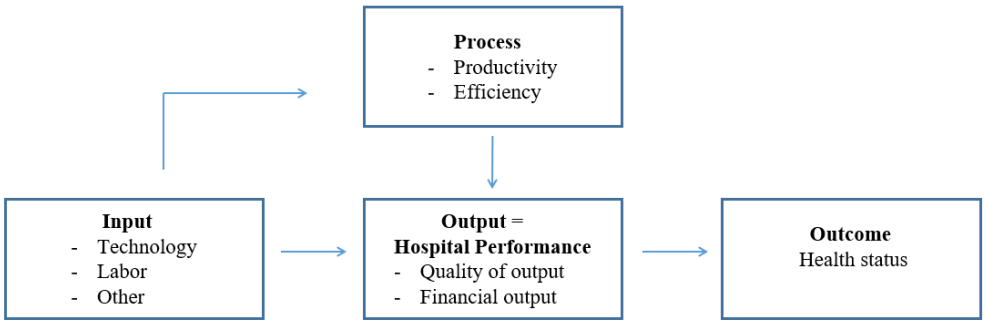

Figure 1. Preliminary Framework of Hospital Performance

2.2 Influence of Medical Technology on Hospital Performance

Considering the mentioned theoretical concepts, there are several ways how technology influences performance in theory. This thesis examines both the effect of medical devices and IT on hospital performance. A medical device distinguishes itself by the following characteristics. First, it has to be used for prevention, diagnosis, monitoring or treatment of a certain health state.

Second, the initial mode of action should not be based on a metabolic, pharmaceutical or immunological process (Kirisits and Ken Redekop, 2013). The performance of medical devices depends heavily on organizational settings, training, competence and experience of the operator (Ciani et al., 2016). IT includes all the information systems in a hospital, both regular and systems designed specifically for the health care sector. Examples of Health IT (HIT) are the Electronic Medical Records (EMR) and Clinical Decision support (CD) systems (Agha, 2014).

Medical technology can mainly improve hospital performance by reducing information asymmetry and uncertainty. For instance, a diagnosis or choice of treatment that a physician makes is very often subject to uncertainty, as a physicians' performance may be prone to errors. An incorrect diagnosis leads to unnecessary costs which the use of advanced technologies can prevent (Harris, 1977). Furthermore, it can reduce the information asymmetry between medical specialists and the hospital, as the medical devices provide more objective evidence for diagnosis and treatment. This may reduce contracting costs between the hospital management and the medical specialists (Borzekowski, 2002). Moreover, medical devices are often used for multiple indications (Ciani et al., 2016). This means that one device can increase efficiency by contributing to the diagnosis or treatment of multiple illnesses. This may shorten the average length of stay of patients or increase the amount of patients that can be treated. These are all theoretical examples of how technology improves the process of a hospital, which in turn increases hospital performance.

There are also ways in which technology may directly influence the hospital outputs. Medical devices can reduce the uncertainty in diagnosis and treatment by helping a physician to provide care more accurately. A more valuable IT system or medical device can immediately lead to better quality of the provided services. Examples of better quality of outputs are more accurate diagnosis leading to better treatment and higher patient satisfaction (Borzekowski, 2002). Another enhancing effect of medical technology is that is should generate cost savings and increase revenues by attracting more patients. Smart technologies, both IT and medical devices, can replace manual work. This should lead to direct cost savings and thus to better performance. Similarly, technology investments are only useful in a few situations. One possibility occurs when the new technology is less expensive and provides more benefits than the old technology, this is the ideal situation. Otherwise, the new technology either provides higher benefits at a higher cost, or less benefits at a lower cost. (Cutler and Mclellan, 2001). Regard that in the

Netherlands no guidelines exist on the adoption of medical devices (Franken et al., 2014). Hence, it depends on hospital decision making which technology will be adopted and to which extent costs increase. Goldstein et al. (2002) argue that an investment in medical technology is the result of operational decision making that coincides with the strategy of the hospital. Hospitals will only invest in health technologies when it improves their performance (Goldstein et al., 2002). Therefore, it is plausible that a hospital makes a cost-benefit consideration in advance of acquiring the technology. A technology should directly save costs and thus increase financial performance, or improve quality of services.

To summarize, medical technology reduces information asymmetry. This leads to the improvement of the productivity and efficiency of a hospital, which improves the quality of services and financial performance. Medical technology can also directly influence hospital performance.

2.3 Theoretical Framework

This section provides some insight in the Dutch hospital system, in order to apply the theoretical concepts to the context of the Netherlands. In addition to the preliminary framework established in section 2.1, many confounding factors interfere in the relation between medical technology and hospital performance. This section presents a theoretical framework about hospital performance.

In the Netherlands exists a third-party payer system. Since 2006 every Dutch person is obliged to have a health insurance that guarantees coverage of a basic package of health care. The government decides which components are included in the package and health insurance companies compete with each other on the market for clients. A hospital is not allowed to choose its patients. Nor is access for patients easy, because patients need to see a general practitioner in advance of visiting a hospital. However, hospitals can attract patients by providing high quality services because patients are allowed to choose a hospital (Blank and Vogelaar, 2004). Hence there exists a certain degree of competition among Dutch hospitals.

The health insurance companies reimburse the amount of health care that hospitals produce. In 2005, the Dutch government decided that hospital costs and revenues should be divided into two segments. The A-segment contains health care which is fully reimbursed by insurers. At the beginning of the year the hospital and the insurer set a budget based on demographic and health care parameters, which the insurer pays to hospital. Prices of treatments are set exogenously and

are uniform. At the end of the year both parties settle the difference: if the hospital makes more declarations and thus has a deficit in the budget, the insurer makes an additional payment and vice versa. The B-segment differs as this provides more space for negotiation between the insurer and the hospital. Prices are not set exogenously, but negotiated between insurer and hospital. The insurance companies procure health care for its clients at different hospitals. Furthermore, declarations are not based on separate treatments, but on Diagnostic Treatment Combinations (DBC), which is a collection of treatments in a specific group. This enhanced the influence of insurers on cost containment as it is more transparent. The two segments together form the total revenue of hospitals. Since 2005, the proportion of A-segment reduced, until the final transition in 2012. From that year, insurers do not provide a fixed budget anymore, but only categorize products in Segment B. Essentially this is a pay-for-performance system (Blank and Eggink, 2011). Smart technologies, especially IT, can provide more insight to the third-party payer about the actions of the hospital. It gives them the leverage to bargain about the value of reimbursement, leading to an incentive for the hospital to produce closer to the marginal cost. In return, this should lead to a better financial performance.

Besides the regulatory system in the Netherlands, there are other factors that mitigate the relation between medical technology and hospital performance in theory. A hospitals' own decision making for instance. The hospital management has to make decisions about essential factors, like the size of the hospital, governance and its strategy. For instance, economies of scale in a hospital can reduce fixed costs and use the capacity more efficiently. On the other hand, a large size may require an increase in variable costs of labor or investments in capital extensions (Dranove, 1998). Furthermore, being a nonprofit institution stresses the need for accountability. The scrutiny from parties external to the organization places extra control system-related demands on nonprofit organizations (Merchant and van der Stede, 2012). Governance is important in every organization and thus as well in hospitals. Especially with a delicate outcome such as health care, a hospital can be publicly scrutinized for mistakes or abusive situations. Similar to governance, every organization needs to develop a corporate strategy to respond to environmental factors and competitive challenges. The strategy incorporates the amount of resource investments, like in technology (Goldstein et al., 2002). Of course location also plays a role. Hospitals situated in an urban region where many people live, probably experience a higher demand opposed to hospitals

in rural regions. The largest proportion of revenues comes from an area in proximity of the hospital (Goldstein et al., 2002).

The theories and the connecting situations I described are applicable to the Dutch system. Dutch hospitals are nonprofit institutions where information asymmetry exists between the administration versus physicians, the patients versus the physicians, the health insurance companies versus the hospital administration and the health insurance company versus the patient. The nonprofit character gives hospitals an incentive to produce their health care above marginal costs. The B-segment approach in the Netherlands however provides health insurance companies a method to navigate hospitals into more efficient production. It puts the principal, the health insurance companies, in a position where they can bargain better performance from hospitals in order to maintain their own profitability. Medical technologies influence hospital performance through reducing information asymmetry between both the hospital administration and medical specialists, as well as the health insurance companies and the hospital administration. This leads to better financial and process outcomes for the hospital. Investments in medical technologies can increase the amount of people that choose for a hospital at lower production costs, which enhances financial performance. Furthermore, in the Dutch system where insurance companies negotiate the reimbursement prices, forces hospitals to only invest in technologies that are cost-effective. This means that the third-party payer has an influence both on medical technology investments and on hospital performance.

2.4 Conclusion

This chapter describes the theoretical concepts and builds the premises on which this thesis continues. The theoretical concepts are the agency theory and the economic theory of nonprofit organizations. The health care industry is subject to extreme forms of information asymmetry between multiple parties. Furthermore, Dutch hospitals are private nonprofit institutions which implies that they serve the public benefit. This makes performance measurement difficult. A hospital uses resources in its process to transform it into outputs, which is the delivery of services. Hospital performance is therefore divided into quality of the output and financial outputs. Technology is believed to influence hospital performance both directly and indirectly through its process. The direct relation assumes that medical technology influences the financial outputs through cost savings and that quality of output increases because of more accurate

delivery of care. Technology is also expected to affect the process of providing health care, through increasing productivity. The increased productivity will improve quality of outputs because of less complications and waiting times. Productivity can enhance the financial output through generating additional revenues. Consequently, the hospital output affects the outcome of the health system, which is personal health. Investments in medical technology are expected to increase hospital performance through reducing the agency problem. The relation between medical technology and Dutch hospital performance is confounded by other factors, like competition and third-party payers. The theoretical framework in figure two visualizes the complex relation. The orange boxes and arrows form the relations that thesis examines. The dotted line from 'hospital decisions' to 'input' means that inputs are not as much a result of decision making, as well as a part of hospital decision making.

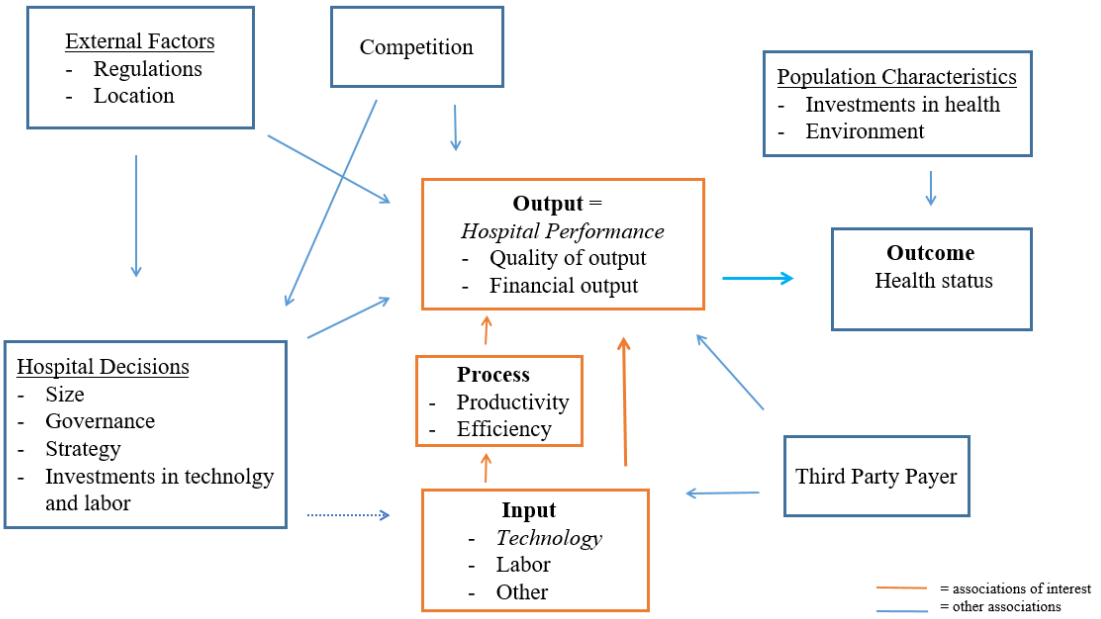

Figure 2. Theoretical Framework of Hospital Performance and Medical Technology

3. Literature Review

This chapter provides an overview of the evidence that has been generated by prior literature. The first paragraph discusses the studies about the influence of medical technology on hospital performance. It examines evidence for the assumed relations in figure two and concentrates on the orange boxes and arrows. Paragraph 3.2 elaborates on medical technology, while section 3.3 explains more about other determinants of hospital performance. These sections therefore describe more about the other relations as visualized in figure two. Paragraph 3.4 concludes the chapter.

3.1 Medical Technology and Hospital Performance

This section gives an overview of the empirical evidence on the influence of medical technology in hospitals. Because this study assumes both a direct and indirect relation between medical technology and hospital performance, the literature review is divided into these two parts.

3.1.2 Direct Relation between Medical Technology and Hospital Performance

Goldstein et al. (2002) examined the effect of hospital location, strategy and technology on hospital performance in the US. They developed a model based on questionnaire responses from hospitals to being in an urban or rural area, through their choices in strategy and operational decisions on technology investments. One of the hypotheses is that technology investments are incrementally associated with hospital performance, after accounting for the effects of location and strategy. The significant results confirm this hypothesis, using hierarchal regression analysis. Technology is defined as a hospitals' ability to provide a particular medical service based on either the equipment and/or skills required to deliver the service. They conclude that technology is positively associated with hospital performance in the form of efficiency and financial leverage (Goldstein et al., 2002). Blank and van Hulst (2008) performed a similar study for the Netherlands during the period 1995 until 2002. They examined the effect of health technology on hospital productivity, by clustering different innovations measured by technology index numbers. Hospitals with a higher index have more advanced technologies. The types of technology varied from medical devices used for diagnosis and treatment, to Information Technology (IT) systems and logistic optimization. The researchers measured productivity by the number of discharged patients. The results indicate that technology used in production processes, like IT, was positively associated with productivity, whereas the innovations directly related to patients, like the medical

devices, was negatively related to productivity. Moreover, they find that some innovations are cost reducing while others are cost increasing. The medical device innovations seem to increase costs for patients that have an outpatient treatment, compared to a cost decline for inpatient care using these innovations (Blank and van Hulst, 2008).

The former studies included medical devices in their dataset of health technology. However, more literature exists on the effects of solely IT. For instance, Gholami, Higón and Emrouznejad (2014) investigated the impact of IT investments on hospital quality in the US. Quality is defined as risk-adjusted mortality and complications during a patients' stay. The researchers found that IT is only significantly decreasing risk-adjusted mortality, but is insignificant for the number of complications. Furthermore, the results indicated that the IT investments have diminishing returns beyond a certain point and after that point decrease operational efficiency (Gholami et al., 2014). Agha (2013) examined the effect of Health Information Technology (HIT) investments on the quality and intensity of hospital treatment, using a large dataset of 3900 US hospitals during the period 1998 until 2005. HIT includes for example electronic medical records. This paper performed a difference-in-difference study with a large dataset and many control variables. She found that HIT is associated with an increase in billed charges and has no impact on cost savings. For the dependent variable 'quality', measured as mortality, readmissions and adverse drug events, she only found little positive evidence (Agha, 2013). Borzekowski (2002) found negative and significant effects of IT on hospital costs, which means that costs declined three and five years after adoption. He also used a large panel dataset of 3000 US hospitals, during the period 1987 until 1994. However, the IT type of interest was different, as Borzekowski examined software based IT and not specifically HIT (Borzekowski, 2002). A literature study by Jones et al. (2014) reviewed 236 articles on the same topic. 147 articles measured the effect of HIT on accumulated 170 types of quality outcomes, another 62 studies reported on efficiency outcomes and the remainder examined safety outcomes. Considering quality outcomes, 82% of the articles reported a significant positive influence of HIT on quality outcomes and 78% of the 46 articles on safety outcomes reported a positive impact. The results on efficiency were more ambiguous, which showed that costs both increased and decreased by the effect of HIT. Earlier application of therapies and shorter length of stay in the emergency department are measures of increased efficiency. Additional documentation resulting in less time for patients however is an example of decreased efficiency. The extensive review reveals that most studies show a positive or mixed

association of the effect of HIT on health care. The authors note however that the understanding of the relation is still lacking, with the consequence that HIT is not used to its maximal potential (Jones et al., 2014).

3.1.2 Indirect Relation between Medical Technology and Hospital Performance

The array of evidence for an indirect relation is much smaller than for the direct relation. However, Li and Collier (2000) performed a comprehensive study on both the indirect relation of medical technology on hospital performance. The researchers separate medical devices and IT in the variables clinical technology and information technology. Subsequently, they regress financial performance on both measures of technology directly, and also through the process and quality of output. Therefore, their model slightly deviates from the model used in this thesis. However, they find that both measures of technology are directly positively influencing financial performance. Furthermore, they test the associations between IT and the process, and medical devices and quality performance. Both seem to be statistically significant. The indirect relation that Li and Collier find is that IT positively influences financial performance through the process. Furthermore, the process also has a significant association with quality of outputs. Financial hospital performance is defined as return on assets, return on investment and operating profit, while process indicators are leadership, empowerment and staff training and competency. Quality of outputs comprises six different measures of clinical outcomes and physician participation. The researchers define technology as investments in five types of medical devices, while IT includes six different systems (Li and Collier, 2000). Although only one piece of evidence for the indirect relation exists, the article shows many similarities with the model of this research.

3.2 Medical Technology

This paragraph provides more information about cost-effectiveness evaluations of medical technologies and about the determinants that influence hospitals to invest in medical technologies. Most of the literature on evaluation of medical devices concentrates on the Cost-Effectiveness (CE). The CE is derived by calculating the Incremental Cost-Effectiveness Ratio (ICER). These studies focus on the considerations of implementing a new technology compared to another (outdated) technology or doing nothing. For example, Wu et al. (2016) compare the CE of several technologies to diagnose thunderclap headache. Dick et al. (2015) evaluate the ICER's of several prevention programs against infection diseases in the US.

However, several factors, both external and device-level, complicate the economic evaluation of medical devices. These factors are not as present during the economic evaluation of pharmaceuticals. Examples of these constraints are the lack of objective data, the supplier market of medical technology and the narrow opportunities to conduct randomized controlled trials. The consequence is that hospitals adopt a certain technology which has proven its worth yet (Kirisits and Ken Redekop, 2013). On the device level, Ciani et al. (2016) argue that the economic value is hard to assess because devices are used for multiple conditions and may only contribute in the early stage of the process (Ciani et al., 2016). Also, the use of medical devices is subject to the professionalism and skills of the physician. Moreover, because of the lack in clinical evidence, health workers frequently have to work with devices of which the manufacturers require suggestions for improvement (Kirisits and Ken Redekop, 2013). In a large in-depth case study containing data from 127 interviews in the UK, researchers found that clinicians and users thought that the medical devices could only be evaluated after extensive use. Even while the industry and media reported that a technology was highly cost-effective (Ulucanlar et al., 2013).

This urges the need for a thoughtful decision making process considering technology investments in hospitals. Blank and Vogelaar (2004) found during 1993 to 2000 that hospitals adopt new technologies shock wise through time, instead of continuously. Furthermore, adoption of technology leads to increased use of medical workers and material supplies, at the expense of nursing workers. This is in line with the visible decrease in average hospital stay, which also implies a decrease in the need of nursing personnel (Blank and Vogelaar, 2004).
Some studies exist on the determinants that influence hospitals to adopt new health technologies. Mas and Seinfeld (2008) studied the effect of managed care, on the procurement of 13 kinds of medical devices. They examined this during the period 1982 to 1995, when managed care expanded in US hospitals. Managed care is a system aimed at controlling health care expenditures. The results show that managed care is negatively associated with the adoption of health technology. For instance, the probability of investing in a MRI scanner is 4.6% lower, for a PET site the probability reduced even with 27%. The results are consistent for all 13 technologies. Furthermore, the probability of diminishment is largest for technologies that are the least profitable to hospitals. This implies that under the influence of managed care, profitability becomes more important in the acquisition of medical devices (Mas and Seinfeld, 2008). Baker and Spetz (1999) examined the same subject and found somewhat similar results. The study

differs as the number of technologies in this study is larger and they grouped the technologies in one aggregated index. Managed care was negatively associated with the level of the technology index (Baker and Spetz, 1999). Baker and Phibbs (2000) studied whether managed care reduced the adoption of one specific technology used for treatment of newborns (neonatal intensive care units), and additionally investigated alternations in quality of care. They found that managed care indeed decreases the adoption of the technology, confirming the previous studies. However, managed care led to a decrease in the mid-level type of the technology and not in the high-level, which meant that health outcomes did not diminish (Baker and Phibbs, 2000).

Another determinant of technology adoption is the health insurance system. A literature review elaborates that a broader coverage of health insurance in a population increases the demand for health care. This increased demand provides an incentive for health technology companies to invest more in R&D to develop new medical devices. Hospitals adopt the technologies easier because of sufficient demand. However, this is a vicious cycle, as advanced technologies also incentivize people to buy health insurance (Weisbrod, 1991). Devers, Brewster and Casalino (2003) examined changes in hospitals' strategy. They found that an emphasis on non-price competition would lead to hospitals overproviding health technologies in order to stay more attractive than the competitor. Also, hospitals may feel inclined to procure a certain medical device based on financial rewards or associated prestige (Devers et al., 2003).

3.3 Hospital Performance

The theoretical framework explained that medical technology is not the only determinant that influences hospital performance. This paragraph elaborates on the empirical evidence on other variables that influence hospital performance. There is a wide variety of articles which examined hospital performance.

For instance, hospital competition affects hospital behavior which results in a different performance. Prior literature shows mixed effects of competition. In the Netherlands for instance, hospital competition had a negative association with health related quality outcomes, but a positive relation with process outcomes. This suggests that hospitals experiencing competition feel pressure on their profitability, which causes them to improve production efficiency (Bijlsma et al., 2011). Another study found mixed results of hospital competition on the quality of inpatient health care (Mutter et al., 2008). While again other studies found positive effects of hospital competition on performance in the form of quality (Sari, 2002 & Kessler and McClellan,

2000). Furthermore, national health policies affect hospital performance. Health care reforms in the Netherlands during the past decades had an effect on cost containment and equal access and outcomes in health care (Schut and van de Ven, 2005). Goldstein et al. (2002) examined, beside the effect of technology investments, also the effect of hospital location and strategy on hospital performance. Their results indicate that urban hospitals are performing better, but that strategy can moderate this relation (Goldstein et al., 2002). Besides technology, the other important resource that a hospital has access to is personnel. In the US, a study found a positive relation between nurse staffing and operating expenditures, but no significant effect on operating profit. On the other hand, non-nurse staffing was associated with both higher costs and lower operating profit (McCue, Mark and Harless, 2003). The compensation scheme of physicians is of importance as well. A literature study of 30 articles examined the effect of a pay-for-performance scheme on quality of care. It shows that the studies with a better methodology found a negative association between this payment scheme and quality of health care. The studies using a weaker method however found a positive association (Houle et al., 2012). Furthermore, Jha and Epstein (2009) found that governance is also correlated with quality of provided care. The researchers conducted a survey among 922 hospital boards in the US about the importance of quality. They measured the prioritizing of quality on the agenda of board meetings, timely reviewing of quality data and whether the hospital had a quality subcommittee. Their dependent variable is a summary score of 19 different quality indicators based on three disease conditions. A board indicating that quality is a priority was significantly associated with high quality performance (Jha and Epstein, 2009).

There also exists research on the relation between financial performance and quality of a hospital. An older study found a positive correlation between a hospitals' operating margin and perceived quality of services (Harkey and Vraciu, 1992). A more recent article shows that quality improvement measures are associated with financial performance in the form of cash flows and costs per case (Alexander, Weiner & Griffith, 2006). Also the other way around, higher costs per patient are associated with quality, expressed as improved patient survival and functional status (Picone et al., 2003). Furthermore, a large stream in the literature about hospital performance concentrates on the effects of ownership (e.g. Bayandir, 2012 & Shen et al., 2005). However, because this thesis solely includes one type of ownership (nonprofit hospitals), I do not discuss these results.

3.4 Conclusion

In conclusion, the academic evidence on the effect of hospital technology is rather mixed. Three studies focused specifically on medical devices, while five studies and one literature review used IT as explanatory variable. The studies use different types of both technology and hospital performance. I take this into account when defining the types of technology and performance in constructing my empirical model. Most studies observe the direct effect of medical technology on hospital performance. One study (of Li and Collier, 2000) finds a positive indirect effect of technology on performance. Despite the fact that only one article provides evidence for an indirect relation, the theory assumes the existence of this phenomenon. Therefore this thesis can strongly contribute to the existing literature by providing additional evidence on an indirect relation. The tables below provide a summary of the discussed studies.

Considering medical technology, both external and device-level challenges exist in the economic evaluation of medical devices. Furthermore, some studies concentrate on the determinants that influence the adoption of technology in hospitals. Some of these determinants are managed care, health insurance and hospital strategy. The paragraph about hospital performance discusses the determinants influencing the dependent variable in this thesis. Among these determinants are competition, national policy, location, hospital strategy, personnel, compensation schemes and governance. Furthermore, a mutual relation exists between financial and nonfinancial performance. This implies that it is important to include control variables in the empirical model.

It is important to note that the literature shows that hospital technology is used both as an explanatory and dependent variable in research. This means that the hypothesized relation between technology and hospital performance is therefore rather complex. Medical technology can both have an influence on performance, but characteristics that are related to hospital performance can also determine the level of available technology. This presumed reverse causality is a problem in determining a causal relation. Furthermore, the examined studies use different variables to define the relation, which implies a risk of omitted variable bias and measurement error. The presence of unobservable factors which causally affect both hospital technology and performance cannot be precluded. However, I try to mitigate these problems by taking into account as many factors as possible. I explain this in more detail in the methodology in chapter five.

Study	Independent Variable(s)	Dependent Variable(s)	Result(s)
		Direct Relation	
Goldstein (2002)	The ability to provide a certain medical service, based on devices and skills.	Process: occupancy rate, efficiency. Financial: financial leverage.	Technology is positively related to hospital performance in the form of leverage and efficiency.
Blank and van Hulst (2008)	Availability of 63 specific innovations, both medical devices and IT.	Process: number of discharges and outpatients adjusted by case-mix. Financial: cost savings	IT is positively related to productivity. Medical devices are negatively related to productivity. Cost increasing for outpatient care. Cost reducing for inpatient care.
Gholami et al. (2014)	Direct expenditures on IT systems.	Quality: risk-adjusted mortality & number of complications. Process: efficiency.	Quality: decreases risk-adjusted mortality. Insignificant for number of complications. Process: decreasing marginal returns of IT investments.
Agha (2013)	Availability of two IT systems: electronic medical records & clinical decision support.	Quality: patient mortality, adverse drug events & readmission rates. Financial: billed charges & cost savings.	Quality: insignificant for mortality, adverse drug events & readmission rates. Financial: increases billed charges and insignificant for cost savings.
Borzekowski (2002)	Aggregate indices of IT systems that are software-based.	Financial: hospital costs three and five years after adoption of the IT systems.	IT systems are associated with decreasing costs after three and five years.
		Indirect Relation	
Li and Collier (2000)	Investments in 5 types of medical devices and 6 types of IT systems.	Quality: clinical outcomes & physician participation. Process: leadership, staff competency + training & empowerment. Financial: ROA, ROI & operating profit.	Direct: both technology measures postitively influence financial performance. Medical devices positively influence clinical quality. IT positively influences process quality. Indirect: IT positively influences financial performance through the process. The process influences quality of output.

Table 1. Summary of prior literature about association of interest

Table two summarizes the most important articles on the confounding factors with respect to the relation between medical technology and hospital performance.

Study	Independent Variable(s)	Dependent Variable(s)	Result(s)
		Medical Technology	
Blank and Vogelaar (2004)	Technology change index.	Input: material supplies, personnel. Process: length of stay.	Technology is adopted shock-wise, not smoothly. Positive relation with medical personnel & material supplies. Negative relation with nursing personnel & length of stay.
Mas and Seinfeld (2008)	Managed care: health maintenance organization enrollment.	13 types of medical devices.	Significantly decreases adoption of technology, consistent for all 13 medical devices.
Devers et al. (2003)	Competitive strategies of hospitals.	Change in expansion behavior.	This qualitative study found an increase in expansion of high-tech inpatient outpatient services. Increase of duplicating services.
		Hospital Performance	
Bijlsma et al. (2011)	Real number of competitors & adjusted to population, distance to hospital.	Process: frequency of tests and diagnosis. Quality: cancelled operations & hip fracture injury.	A significant positive association with process indicators. An insignificant negative association with outcome indicators.
Goldstein et al. (2002)	Urban / rural dummy. Surveys to hospitals about their strategy.	Process: occupancy rate & efficiency. Financial: financial leverage.	Significant association between location and performance. Insignificant relation between strategy and performance. Significant relation between interaction of the two and performance.
McCue et al. (2003)	Nurse staffing & non-nurse staffing.	Financial: operating expenses & operating margin.	Significant increase in expenses, insignificant decrease in profit.
Jha and Epstein (2009)	Governance: board opinion on training, expertise in quality, quality importance, evaluation of CEO performance.	Summary score of quality, consisting of 19 parameters for care in 3 clinical conditions.	Significant correlation between prioritizing of quality and high quality performance.

Table 2. Summary of prior literature about confounding factors

4. Hypothesis Development

This chapter defines the hypotheses I use in order to answer the central research question. The hospital market is characterized by many principal-agent relations. Between a principal and an agent exists information asymmetry, while both are effort averse and utility maximizing (Pontes, 1995). A hospital has multiple principal-agent relations. The hospital administration for instance acts as a principal towards the relation with the medical specialists. Where the administration

desires a good overall performance of a hospital, the major interests of a medical specialist are the wellbeing of a patient and their own situation (Harris, 1977). Furthermore, the economic theory of nonprofit firms is consistent with hospital behavior. In general, Dutch hospitals are not-for-profit institutions. This has as a consequence that the organizations do not distribute their profit to their owners and that their purpose differs from for-profit organizations (Merchant and van der Stede, 2012). The objective of hospitals is to serve the public, which leads to many stakeholders with conflicting interests. Because of this different purpose, a hospitals' utility function also includes quality of services. Therefore a hospital will not only produce profitable products (Newhouse, 1970). Consequently, this leads to difficulties in measuring performance, as goals are unclear and certain tradeoffs need to be made to satisfy every stakeholder to some extent (Merchant and van der Stede, 2012). The prior literature is also inconclusive in choosing a proxy for hospital performance. Some studies examine only financial performance, or quality outcomes. Examples of indicators used for financial performance are cost savings (Agha, 2013 & Blank and van Hulst, 2008), or financial returns and operating profit (Li and Collier, 2000) and financial leverage (Goldstein, 2002). In terms of quality of health and process quality the studies are using different proxies as well.

Albeit that performance measurement is rather difficult, it is possible to construct some clear associations. A hospital uses resources like capital, technology and labor as inputs in its process. A hospital process includes all aspects of how the service is delivered to the customer (Li and Collier, 2000). As a result of the process, outputs are generated, which are the number of constant-quality actions or activities (Schreyer, 2012). The output is equal to the performance of a hospital. It comprises both the financial performance of a hospital and the quality of the delivered services. Although it is straightforward to think that a hospitals' performance is defined by the health status of a patient, this is not entirely the case. Health is the ultimate outcome of a hospital and the health system as a whole, but it is not an output. An outcome corresponds to the purpose for which goods and services are used and an output corresponds to the goods and services themselves (Schreyer, 2012). Many factors affect personal health, factors that are independent of medical care provided by hospitals, like investments in one's own health. Therefore, hospital performance is best measured by objective indicators that are produced by the hospital itself.

Medical technology is expected to reduce the agency problem and influence the performance in several ways. Hospital technology can reduce uncertainty between hospital administration and medical specialists (Harris, 1977). Some technologies offer the possibility to work more efficient than physicians. For instance, medical devices are often used for multiple indications (Ciani et al., 2016). This means that a single device can increase efficiency by contributing to the diagnosis or treatment of multiple illnesses. Consequently it should reduce the length of stay, accelerate and multiply the number of treatments, hence increasing hospital productivity and efficiency. For example, Blank and van Hulst (2008) found that IT systems are positively related to the number of discharges. Goldstein et al. (2002) also found an increase in efficiency. Therefore I generate the first hypothesis.

H1: *investments in medical technologies have a positive influence on the process of Dutch hospitals.*

Hospitals investment in medical technology as a result of operational decision making that coincides with the strategy of the hospital. Hospitals will only invest in health technologies when it will improve their performance (Goldstein et al., 2002). Hence it is expected that hospitals make a solid business case before acquiring new technology. It depends on hospital decision making to what extent costs increase as a result of technology adoption. Technology in hospitals can generate cost savings by preventing unnecessary treatments or attracting additional patients which generates more revenue. Furthermore, technology may reduce contracting costs between the hospital management and the medical specialists, because of reduced uncertainty (Borzekowski, 2002). The evidence is not unambiguously. Blank and van Hulst (2008) found mixed results on the effect of medical technology on financial performance, but did find that especially IT was associated with cost savings in inpatient health care. Agha (2013) only showed negative and insignificant findings. However, the majority of the studies reports a positive influence of technology on financial performance (Li and Collier, 2000, Borzekowski, 2002 & Goldstein et al., 2000). Therefore I expect technology to have a direct positive influence on financial performance.

H2: *investments in medical technologies are positively associated with financial performance of Dutch hospitals.*

Through more possibilities for accurate diagnosis and treatment options that advanced technologies offer, I expect quality of delivered products to increase as well. For instance, a diagnosis or choice of treatment that a physician makes is very often subject to uncertainty, as a human can easily make a mistake. An incorrect diagnosis leads to unnecessary health depreciation which advanced technologies can prevent (Harris, 1977). IT systems can change the way that physicians, patients and other stakeholders interact. For instance, hospital IT systems can provide clinical information that will improve patient satisfaction (Li and Collier, 2000). Gholami et al. (2014) confirms an improvement of quality by showing that IT is associated with a decrease in risk-adjusted mortality rates. Thus, because innovative technologies are more advances than current technologies, I expect that quality of output directly increases.

H3: *investments in medical technologies are positively associated with quality performance in Dutch hospitals.*

Besides the assumed direct relation between medical technology and hospital performance, I expect a mediating effect of the process. The theoretical framework clearly explains the effect of the input (technology) on the process, which influences output (performance). Some outputs of both quality and financial sort, are a result of the process performance. When a hospital uses its capacity more efficient, it can treat more patients and thus reduce waiting times. The amount of time a patient has to wait has an influence on his health status (Guttman et al., 2011). Providing medical care to a patient at an early stage can prevent a deterioration of the quality of outputs, as it is easier to treat the patient. Furthermore, an accelerated process increases the amount of patients, which leads to better revenues. Li and Collier (2000) examined the indirect relation between process quality and financial performance. They found a positive association, additional to a direct relation between IT and financial performance. Furthermore, their results show an effect of the process on quality of outputs. It would thus be insufficient not to test the mediating effect of process in the association of technology and performance. Therefore, I construct the following to final hypotheses.

H4: *the process has a mediating role in the relation between investments in medical technologies and financial performance in Dutch hospitals.*

H5: *the process has a mediating role in the relation between investments in medical technologies and quality performance in Dutch hospitals.*

5. Methodology

This chapter explains the research designs of the methods that this study uses to identify the effect of hospital technology on performance. Paragraph 5.1 explains the qualitative part of the method, while paragraph 5.2 elaborates on the quantitative part, the data collection and model specification.

5.1 Qualitative research design

The research design in this study consists of both a qualitative and quantitative analysis. The reasoning behind this choice is that hospital performance is subject to many factors. Therefore a risk of omitted variable bias is present. Furthermore, the literature review shows mixed results. The understanding of the link between technology and hospital performance is still uncertain (Jones et al., 2014). It seems that the quantitative studies performed on this topic have not yet discovered a proper explanation for the mixed results. The qualitative analysis provides more profound insights about how technology plays a role in driving hospital performance. The aim of the case study research is not to test the hypotheses, but to explain the results of the quantitative analysis. I use it as a first confirmation or denial of the regression results.

I perform the qualitative part by a case study of multiple hospitals. A case study investigates a phenomenon in depth within its real-life context, especially when the boundaries between the phenomenon and the context are not clear. Moreover, a research design using multiple methods, like interviews and regression analysis, can address a richer and stronger array of evidence (Yin, 2014). The research question of this study is *What is the effect of investments in medical technology on the performance of Dutch hospitals?*. 'What' questions are in general more related to quantitative research (Yin, 2014). However, the case study is designed to answer 'how' and 'why' questions. The analysis of multiple cases allows for comparing differences between the topics of interest. There is no requirement that the selected cases have to be representative for the entire Dutch hospital industry. Multiple cases however do improve generalizability and provide a better understanding of the constructs of interest.

5.1.1. Data Collection

Data collection occurs through two sources. The use of multiple data sources increases the internal validity of the research (Yin, 2014). The primary source is conduction of interviews, which will have a semi-structured character. This means that the interview consists of a set of

questions that support identifying the key issues, but it also allows to diverge in order to pursue a response or idea in more detail. This method is especially used frequently in health care (Gill et al., 2008). Considering the findings of the literature overview and review, the objectives of the case studies are:

- Explore how a hospital identifies the need for new technology investments.
- Identify any guidelines on the procurement of technologies by hospitals.
- Identify how a hospital designs a business case for approval of new technologies.
- Explore how a hospital evaluates the use of new technologies after implementation.
- Identify which performance indicators are important to hospitals and which other factors influence the effectiveness of medical technology.

The appendix presents the structured interview questions. Depending on the course of the interview I may change or add certain questions, because of the semi-structured setup. In advance of the interview, the interviewee receives the list of questions in order to prepare or check the questions. Afterwards, the interviewee can revise the processed answers of the interview and if necessary edit something.
The secondary source of data consists of additional documentation, like annual reports or press releases from the hospitals. I gather this to obtain a completer view on the discussed topics during the interviews.

5.1.2. Case Selection

At the moment of conducting this research, there are 116 hospitals in the Netherlands, of which nine academic centers, 84 general and 23 categorical hospitals. The 107 general and categorical hospitals are the starting point for the case selection. The unit of analysis are the hospitals. I take into account both the available time and the strength of the results in the selection of the cases. Three hospitals are willing to participate in the research, which are shown in the table three. The Ikazia hospital is a general hospital located in Rotterdam. The ‘Havenziekenhuis’ is also a general hospital located in Rotterdam, but it is a subsidiary of the Erasmus Medical Center, which gives a different dynamic. The Sint Maartenskliniek is a hospital of the categorical sort, specialized in posture and movement medicine. It is located in Nijmegen, Boxmeer and Woerden.

Case no.	Name of Hospital	Interviewee
Case 1	Ikazia Ziekenhuis	Mrs. Saskia Meeuwsen (Head of procurement department)
Case 2	Havenziekenhuis	Mr. Ron van der Pluijm (Head of facilities management)
Case 3	Sint Maartenskliniek	Mr. Dr. Mark van Houdenhoven (Board president)

Table 3. Participating hospitals and representatives

5.2 Quantitative research design

To measure the direct effect of hospital technology on hospital performance in a quantitative manner, I will use an Ordinary Least Squares (OLS) regression, while using panel data. The unit of analysis is therefore hospital-year ("it"). The characteristic of panel data is that it contains repeated observations of the same units over time. This makes it possible to estimate both the variation in hospital performance due to technology availability *within* hospitals over time and *between* different hospitals. When using cross-sectional data it is only possible to measure the variation between hospitals. Another advantage of using panel data over cross-sectional data is that it increases the efficiency and reliability, because the same institutions are observed over multiple years. Specifically I will use either a random effects model or a fixed effects model.[1] The random effects model exploits the correlation between the error terms, but only when the zero conditional mean assumption holds. The fixed effects model on the other hand is useful when the technology investments change enough over time, as this method eliminates all constant factors over time which can be confounding (Wooldridge, 2014).

Hypotheses four and five require a different method. The purpose of analyzing these hypotheses is to evince a mediating effect of the process in the relation between medical technology and hospital performance. I do this using the bootstrap method. This method computes different confidence intervals and determines the indirect effect by repeatedly multiplying the regression coefficients (Long and Freese, 2001).

[1] The statistical Hausman test will indicate the final decision on using either the random effects, or fixed effects model.

5.2.1 Data Collection and Sample Selection

I collect the majority of the data from a publicly available dataset 'DigiMV'. Every health providing organization in the Netherlands needs to submit details about both annual statements and nonfinancial information yearly. Hospitals are obliged to provide the information by law. The organization Annual Reports Health Care (*Jaarverslagen Zorg*) is controlled by the Ministry of Health and publishes the DigiMV dataset each year. The data are available for the years 2011 – 2014. Considering this availability constraint, I collect data from other sources for the same time frame. The population numbers are retrieved from the Central Bureau of Statistics (CBS). The Dutch Authority of Health Care (NZA) provides the Herfindahl-Hirschman index number of health insurance companies per province. The Dutch Hospital Data (DHD) provides data about the percentage of medical specialists which received a performance review. DHD is a part of the Dutch Association of Hospitals (NVZ).

I choose to include both general and categorical hospitals in my data. I exclude the academic hospitals because these hospitals are subject to a different case-mix than other hospitals. This means that patients that are admitted to the academic hospitals in general suffer worse conditions than people in general or categorical hospitals. Furthermore, the academic hospitals can be seen as a last resort, where patients are sent to when other hospitals indicate that they lack knowledge or skills to treat a certain patient. As I am unable to identify the case-mix per hospital, including the academic hospitals may confound the results as both their technology level and hospital is presumably strongly affected by case-mix of patients. Furthermore, I exclude the revalidation centers as these institutions serve a different purpose than general and categorical hospitals in the Netherlands.

5.2.2 Independent Variable

Hospital technology is the variable of interest in this research. I use yearly investments in euros in medical devices and IT per hospital as a proxy for medical technology (*TECHINVt-1*). Specifically, the investments include all machines and installations, and technical systems attributional to the operational activities of a hospital. Important to note is that I use the amount of investments in t-1, thus the year before the year of measurement. I use a lagged variable to prevent any reverse causality or simultaneity.

There are a number of reasons to choose for the amount of investments over other proxies. First, it is certain that the total investments reflect the total amount of hospital technology that a hospital bought. I measure the effect of both medical devices and IT, which comprises many machines, installations and other devices. Therefore it can be hard to capture all the available technology in a hospital. Second, there is no data directly available about the number of devices or systems a hospital owns. Hand collecting these data is not possible within the time scope of this thesis. The investment data is both available from the DigiMV dataset, as well as from the public annual reports of hospitals. Third, the investments in technology include the educational investments as well, which is an important factor in establishing effectiveness of a specific technology (Scalese et al., 2007 & Hernandez et al., 2004). Finally, several technology indices have been developed, based on the absolute number of present technologies. However, they are all limited in some ways (Spetz and Maiuro, 2004). Furthermore, an important part of the motivation of this thesis is to examine whether technology in hospitals is worth the investment. It makes therefore more sense to measure the invested amount than individual numbers of medical devices and IT systems.

5.2.3 Dependent Variables

All the dependent measures are retrieved from the DigiMV dataset. The theoretical framework shows that there are three important types of performance; process, financial and quality. As explained, the academic literature use different kinds of hospital performance and therefore proxies. For the measurement of process performance I use average length of stay (*LOS*), the number of discharges (*discharges*), the number of unfinished DBC's (*nonclosed_DBC*) and the number of patients with at least one closed DBC (*min_closed_DBC*). These proxies have been used before to measure the performance of the process (e.g. Blank and van Hulst, 2008 & Blank and Vogelaar, 2004). It measures the productivity of a hospital, which indicates how many patients it can process in a given time.

Likewise for financial performance exist a variety of indicators. Some studies use costs or costs savings (e.g. Borzekowski, 2002, Blank and van Hulst, 2008 & Agha, 2013). Goldstein (2002) uses financial leverage and efficiency. Based on the literature and reasoning, I choose profitability (*profit*), solvability (*SOLV*) and operating costs (*oper_costs*) as proxies for financial performance. Solvability is calculated as total equity divided by total assets. Even though

hospitals are not allowed to distribute their profit to the owners, profitability is still an important factor to hospitals. First, hospitals are liable to other parties. Their financial situation needs to enable hospitals to repay debt. Second, profitability allows hospitals to invest in technologies, buildings or other quality improvements. This is necessary to remain competitive relative to other hospitals. The solvability is a good indicator for financial health in the longer run, while operating costs and profitability are indicators for the short run.

The empirical evidence tries to capture quality performance by using (risk-adjusted) mortality, readmissions and complications during a patients' stay (e.g. Agha, 2013 & Gholami et al., 2014). I choose to use readmission rate (*readmissionrate*) as main variable of analysis to measure quality. The amount of readmissions is rather an objective measure, because it indicates the effectiveness of the treatment. The rate is calculated by the dividing the number of readmissions by the number of first visits. I specifically do not choose for any other variables to represent quality, because many measures depend heavily on the case-mix in a hospital. Overall health standardized morality rates are used widely because many believe that it is adjusted for the case-mix of patients. However, research indicates that the health standardized mortality rates are far from flawless (Shashian et al., 2010). In the Netherlands hospitals and other stakeholders still debate about the usefulness and fairness of these mortality indicators (Laan et al., 2015). Therefore I use the readmission rate as a proxy for quality, because it relates less to case-mix and more to the effectiveness of a treatment.

5.2.4 Control Variables

Based on the theory and the empirical evidence I include a set of control variables. Furthermore, I test all control variables on their statistical additional value to the final model. Excluding control variables would cause a bias in the results, because it is obvious that hospital technology is not the only factor that influences hospital performance. If the model only incorporates the variable of interest it eliminates the context of reality. The theoretical framework indicates which control variables are needed. The purpose of the these variables is therefore to control for factors that can confound the results. Table four lists all the control variables including its justification.

Control Variable	Source	Justification	Used for
Urban / Rural dummy	DigiMV	Goldstein et al. (2002), control for location.	H1 – H3
General / Categorical hospital dummy	DigiMV	Goldstein et al. (2002), control for strategy.	H1 – H3
Number of competitors per COROP region	CBS	Bijlsma et al. (2011), control for competition.	H1 – H3
Absenteeism	DigiMV	Jha and Epstein (2009), control for quality of medical specialists.	H1 – H3
Number of beds per hospital	DigiMV	Agha (2013), control for size.	H1 – H3
Number of medical specialist FTE per hospital	DigiMV	Agha (2013), control for size.	H1 – H3
HHI of insurance companies per province	NZA	Blank and Eggink (2011), control for bargaining power health insurers.	H1 – H3
Number of DBC's in B-segment	DigiMV	Blank and Eggink (2011), control for bargaining power health insurers.	H1 – H3
% of medical specialists that had a performance review	DHD	Jha and Epstein (2009), control for governance.	H1 – H3
Remuneration per FTE	DigiMV	Jha and Epstein (2009), control for governance.	H1 – H3
Medical FTE per 1000 persons per COROP region	DigiMV & CBS	Agha (2013), control for capacity of possible demand.	H1
Profit in t-1	DigiMV	Goldstein et al. (2002), control for financial strategy.	H2
Year fixed effects	General	Control for year fixed effects when using random effects model	In RE models

Table 4. Control Variables

Table four explicates all the control variables added to the models in the analysis. The urban / rural dummy (*urb_dum*) is based on the criterion whether a hospital is based in either Eindhoven or in the urban area *Randstad*, which includes the area and cities Amsterdam, Rotterdam, Utrecht and the Hague. The number of competitors (*nr_comp*) is calculated per COROP region. This is a division that is especially used for research by the CBS, because it represents a region with often one urban heart where the COROP population has access to certain services, like a hospital (CBS, 2015). The Herfindahl-Hirschman Index (HHI) (*hhi_ic*) measures to what extent health insurance companies are concentrated per province. It is calculated by accumulating the market shares of

the insurance companies, which indicates their total presence per province (NZA, 2014). Together with the number of DBC's in the B-segment (*bsegment*) it controls for the bargaining power of the health insurance companies. Governance is controlled for by the variable percentage of medical specialists that received a performance review during a year (*perf_rev*), together with the height of their remuneration (*remun*). When the Hausman test indicates that I should use the random effects method, I include year fixed effects. It controls for possible exogenous events in a year that could have a confounding effect on hospital performance, like an infection disease.

5.2.5 Model Specification

HPERF measures hospital performance, which represents all the dependent variables. *TECHINV*t-1 represents the medical technology investments. To avoid the probability of reverse causality, the technology index is a lagged variable, measured in year t-1. The model I use for testing hypothesis one is:

$$HPERF_{it} = \alpha_{it} + \beta_1 * TECHINV_{it-1} + \beta_2 * \text{i}.gen\_hosp_{it} + \beta_3 * beds_{it} + \beta_4 * mfte\_1000p_{it} + \beta_5 * \text{i}.urb\_dum_{it} + \beta_6 * med\_fte_{it} + \beta_7 * \text{i}.nr\_comp_{it} + \beta_8 * hhi\_ic_{it} + \beta_9 * bsegment_{it} + \beta_{10} * remun_{it} + \beta_{11} * perf\_rev_{it} + \varepsilon_{it} \quad (1)$$

Where $HPERF_{it}$ in model one represents four types of process performance: average length of stay (*LOS*), the number of discharges (*discharges*), the number of unfinished DBC's (*nonclosed_DBC*) and the number of patients with at least one closed DBC (*min_closed_DBC*). I include the variable *mfte_1000p* only in model one. It stands for the amount of medical specialist fte per 1000 people in a COROP region, which covers capacity for possible demand. This is useful in hypothesis one, because capacity can play an important role in process performance.

Hypothesis two challenges the effect of medical technology on financial performance. Model two includes three types of hospital performance which are profitability (*profit*), solvability (*SOLV*) and operating costs (*oper_costs*). Furthermore, I additionally include the variable profit in the year t-1, to control for the effects of financial strategy or trends that occur in the hospital (Goldstein et al., 2002).

$$HPERF_{it} = \alpha_{it} + \beta_1 * TECHINV_{it-1} + \beta_2 * \text{i}.gen\_hosp_{it} + \beta_3 * beds_{it} + \beta_4 * profit_{it-1} + \beta_5 * \text{i}.urb\_dum_{it} + \beta_6 * med\_fte_{it} + \beta_7 * \text{i}.nr\_comp_{it} + \beta_8 * hhi\_ic_{it} + \beta_9 * bsegment_{it} + \beta_{10} * remun_{it} + \beta_{11} * perf\_rev_{it} + \varepsilon_{it} \quad (2)$$

The third model attempts to identify the effect of medical technology on quality of output, hence testing hypothesis three. In this model *HPERF* represents the readmission rate of a hospital. All control variables according to the theoretical framework are included in the model.

$$HPERF_{it} = \alpha_{it} + \beta_1 * TECHINV_{it-1} + \beta_2 * \text{i}.gen\_hosp_{it} + \beta_3 * beds_{it} + \beta_5 * \text{i}.urb\_dum_{it} + \beta_6 * med\_fte_{it} + \beta_7 * \text{i}.nr\_comp_{it} + \beta_8 * hhi\_ic_{it} + \beta_9 * bsegment_{it} + \beta_{10} * remun_{it} + \beta_{11} * perf\_rev_{it} + \varepsilon_{it} \quad (3)$$

Hypotheses four and five investigate whether the process indicators are mediators in the relation between medical technology and financial and quality performance of hospitals. I will use the *HPERF* variables *profit*, *SOLV*, *oper_costs* and *readmissionrate*.

5.3 Conclusion

This thesis uses both a case study method and a panel regression analysis. The qualitative research aims at providing more insight in the topic. It aims on giving a first confirmation or denial of the quantitative results. During the case study hospitals are the unit of analysis. Interviews with three hospitals are conducted, which makes it a multiple case study. The interviews have a semi-structured design. The regression analysis is used to test the hypotheses. I use an OLS regression method with panel data during the period 2011 – 2014. The dependent variable is the amount of investments in technology by a hospital in the year t-1. Hospital performance is conform the theory divided into three categories and eight dependent variables. The models are complemented with a set of control variables. The appendix shows the Libby Boxes used to describe the analysis in this thesis.

6. Case Study Results

This chapter provides the empirical findings of the qualitative part of the research. The first three paragraphs are structured by case and the last section provides the cross-case conclusions. Each case description starts with some general information about the hospital and the interviewee. The description of the case continues with the procurement process and investment decisions of medical technology, the evaluation of technology and indicators influencing the performance.

6.1 Ikazia Hospital

Organizational Context

The Ikazia hospital is built on a Christian fundament and exists since 1968. The hospital has a co-operative structure with members on which it can rely for funding of extraordinary projects. There is only one executive and a supervisory committee is present. The capacity comprises 359 beds and the labor force consist of approximately 1350 people. The hospital provides 48 types of health care, which makes it a general hospital. Even though the hospitals is categorized as general, it had certain aspirational goals to distinguish itself through several specialisms. In the policy plan of 2009 – 2014, Ikazia hospital states that it specifically wants to improve among others the policlinics oncology, diabetes, liver/stomach/intestine and build a mother-child center for infant care. I conducted an interview with mrs. Saskia Meeuwsen, who is the head of the procurement department of the Ikazia hospital. She has been active in this position since two years.

The Need for Medical Technologies

The demand for new technologies generally comes from the medical staff working at a certain department. The hospital hosts an annual investment round, where every member of the personnel receives the opportunity to request for a certain investment. The hospital has a fixed budget assigned to specific kinds of investments, for example medical devices.
"*The sum of the value of the requests is always higher than the investment budget*".
Therefore the applicants have to include information to support their proposal. These proposals are evaluated by a specific investment committee. This committee consists of medical specialists and management.

Guidelines Concerning Procurement

The Ikazia hospital has implemented the covenant medical technology quite recently. This covenant contains guidelines about every procedure that a hospital should implement. It does not describe any detailed processes that a hospital should follow, therefore the hospital is free to implement its own regulation considering the details per procedure. Furthermore, the aim of the covenant is to ensure safety and not cost-effectiveness.

"*Since 1.5 years the hospital works according to the protocol of the 'Covenant Medical Technology'. I helped with the introduction of this procedure. We are still improving the details of this procedure, but in general it is working very well*".

After the proposal round, the investment committee organizes a two-day event where the applicants can defend their proposal. Subsequently, the committee creates a list with prioritized projects. Some proposals need more intensive evaluation, because of additional exploitation costs. The hospital evaluates this in consultation with the procurement, technical service, ICT, hygiene departments, together with the party that serves the patient interests. There is a standard form with requirements that needs to be filled out. The investment committee needs to make a final decision based on the complete file. Furthermore, the hospital always tries to collect multiple offers from suppliers, in order to generate bargains. "*In general I can say that the process works very smoothly and all parties know what is expected from them*".

Business Case

Since the implementation of the new procurement system (1.5 years ago), the Ikazia hospital makes a business case in advance of investing in a new technology. In the business case it mainly compares the current situation to the expected future situation. The case contains information about product specifications and the argumentation from the medical specialists. It is not common to include other variables yet, like the new amount of patients the hospital will be able to treat. "*Our business case is not that thorough yet as we do not make a forecast of the total DBC*s".

However, when the medical device that the hospital wants to invest in requires the procurement of additional disposables, Ikazia makes a forecast of the amount of patients it expects to visit their hospital. It allows the hospital to accurately budget all the exploitation costs.

"*An example of when we took cost savings into account was when the Orthopedics department needed a new device, which would mean that the third nurse assistant in the Operation Rooms (OR) would become redundant. We included this cost saving, as well as the additional costs of new disposables. However, it is not the standard approach to include cost savings when we make investment decisions*".

As already explained, the requested value of investments exceeds the budget. When the hospital needs to choose, Ikazia hospital gives priority to replacing medical devices based on their

lifetime. What is left of the budget is divided between investments based on their urgency and the importance of the argumentation. The most important indicators that are taken into account are quality and safety for the patients, but technology costs certainly also plays role. According to mrs. Meeuwsen, the hospital recently added the frequency of usage as an indicator. Furthermore, the hospital keeps the aspirational goals in mind when investing in new technologies.

"*In our hospital we mainly replace medical technology because it is necessary. However, we do look at the attractiveness and the quality of our hospital. An example is that we extended two beds in our Intensive Care (IC) department in order to receive a certain qualification. Furthermore, a few years ago we built a brand new mother-child center*".

Evaluation of Medical Technologies

The hospital does not evaluate the effectiveness of the medical technologies yet. According to mrs. Meeuwsen, it is a goal for the future to evaluate the purchasing process, the quality of the medical devices and the costs of the technologies. In the past the hospital sometimes purchased medical devices that, once installed, have not been used frequently. However the financial incentive to pay more attention to the business case in procuring new technologies increased. Therefore, Ikazia currently performs more intensive evaluations on the investment proposals.

"*On the other hand, we do not take many learnings from the unused devices, as I think that the circumstances are very specific per device*".

The annual report 2011 includes a brief evaluation of innovative technologies. However, it seems that evaluation does not happen on a structural base.

Performance Indicators

The hospital does not employ one important performance indicator, but a mix of performance indicators. There is no protocol to indicate which measures are the most important. However, the hospital indicated in its policy plan that there are three important quality indicators. First, the logistic part of the process, which includes for instance waiting time and lead time. Furthermore, safety and the attention given to a patient are important performance contributors. The annual report of 2011 states that it gives high priority to performance indicators which coincide with their aspirational goals. The Ikazia hospital also refers to the performance indicators of the Inspection of Health Care (*Inspectie Gezondheidszorg,* IGZ) Factors that contribute to the

effectiveness of medical technologies are education and testing before adoption, according to mrs. Meeuwsen.

6.2 Havenziekenhuis

Organizational Context

The Havenziekenhuis, which means ‘port hospital’, exists since 1927. It is an independent subsidiary of the Erasmus Medical Center, which means the hospital has direct access to advanced medical specialists. The hospital provides 23 types of medical care, which makes it a general hospital as well. Medical care concentrates on diseases that are highly prevalent, in order to provide good quality care through experience. The Havenziekenhuis has one board member and a supervisory committee. The multiannual aspirational goals focus on tropical- and travel medicine, elderly and basic health care. In 2012, the hospital set an aspirational goal in the context of technology. The aim is to digitalize patient related information. The hospital has a capacity of 260 beds and 769 persons as personnel. The interviewee was mr. Ron van der Pluijm, who is head of the facilities management department since September 2010. The Committee Medical Technology is a part of this department.

The Need for Medical Technologies

In principle do physicians indicate the need for new technologies. Each year the physicians need to make a list with the desired replacements or new purchases, indicating the priority low, medium or high. Because het Havenziekenhuis is a subsidiary firm, proven technology forms the largest share of the invested technologies. It is a relatively small hospital.

Guidelines Concerning Procurement

The “Medical Instrumental Service” is responsible for the management and maintenance of all the medical devices in the hospital. The policlinics themselves are responsible for the procurement of technology. Het Havenziekenhuis practices a very comprehensive guideline for procurement of technology. To summarize, when this proposed device is a simple replacement, the investment committee takes care of the proposal. In the case of a new device, the physician has to make a business case, which needs board approval. When the board approves, the new device needs to be administrated at the procurement department. The administration includes among other things a full overview of the requirements of the new device, as well as a justification to purchase it. Besides the procurement department, other departments need to

evaluate the order and if necessary complement it with additional requirements, like e-learnings. Once the procurement has been completed, all the stakeholders receive instructions on the maintenance and use of the device. Before the device is put into operation, the Medical Instrumental Service controls the device on its reliability. Furthermore, the hospital tries to obtain procurement bargains when it buys on a large scale.
Sometimes a hospital makes a deal with the supplier of medical technology in order to obtain a financial gain. This agreement delivers benefits in the form of technology and the hospital tries to obtain the lowest prices possible.

Business Case

The hospital makes a business case only when it invests in new technologies, not when it invests in proven technologies. It retrieves data to support the business case from its own information; the patient data. In case of a regular replacement, the same device is most often equipped with new features. The committee that needs to evaluate the request for a replacement, debates about the additional benefits of these features. In this process the committee might use data from similar hospitals that already own the device. The process is different for innovative technologies.

"*We try to calculate all the relevant costs and benefits, but the factor that contains the most uncertainty is the number of patients. Opposed to the Erasmus MC, the technologies in our hospital need to be profitable, as we provide more regular treatments. Therefore, we make assumptions about the number of patients that will use the device. The assumptions however are hard to prove and thus it is difficult for the board to approve the estimations*".

The most important variable in the investment decision is safety. Cost-effectiveness is important when investing in innovative technologies. However with the majority of the investments, namely the replacements, cost-effectiveness is subordinate. The value of the amount of investment requests that the hospital receives each year is three times larger than the investment budget. Hence this restraint leads to the hospital choosing between options based on safety and urgency. The Havenziekenhuis also evaluate devices from different suppliers and discusses the investments with the Erasmus MC to achieve possible economies of scale.

"*We examine which department needs a replaced device the most, based on safety risks and improved quality for the patient. We do not make a business case when the technology is not innovative*".

The health insurance company also plays a role in the process. It decides the maximum compensation for a treatment which includes costs of using a medical device. The hospital takes the amount of the compensation into account when designing the business cases. At a constant production level, the insurance company reimburses a lower amount.

"*I think most hospitals, at least our hospital, suffer from a decrease in the amount of compensation*".

Furthermore, production volumes are important to insurance companies, because more experienced medical staff can accelerate the treatment.

Evaluation of Medical Technologies

The hospital performs evaluation on the investments to a certain extent.

"*We do evaluate whether a business case indeed turned out to be profitable. However, we do not evaluate on a detailed level. The hospital only examines the costs and benefits on an accumulated scale. There is certainly room for improvement on this topic*".

As explained, the hospital takes the number of potential new patients into account in its business case. This is also a subject in the evaluation. The Havenziekenhuis also promotes actively to primary physicians and through other channels that it is providing new kinds of treatments, in order to attract new patients. Furthermore, according to mr. van der Pluijm, it is very important to provide insight in the costs of treatment to medical specialists. Many physicians do not think about the costs of a treatment or lab experiment.

"*It works to make costs visible to physicians. We that it helps to contain costs, as physicians will think twice about the necessity of a certain treatment next time*".

Performance Indicators

"*Every hospital has a 'quality and safety' department and several institutions require information about quality and safety indicators. For our hospital, the wellbeing of the patient is the most important. I think the readmission number is a good proxy for the effectiveness of a treatment*".

The annual report of the Havenziekenhuis refers to the IGZ for the relevant performance indicators. The hospital emphasizes that the wellbeing of a patient is the most important indicator

of effectiveness and that trust of the patient means everything. Factors that play a role in the effectiveness of technology are education, digitalization and innovation.

6.3 Sint Maartens Clinic

Organizational Context

The 'Sint Maartenskliniek' is a categorical hospital, located in Nijmegen, Boxmeer and Woerden, founded in 1936. The hospital is specialized in movement and posture health care, it has centers for orthopedics, rheumatism and revalidation. The clinic states that it is the institution with the most advanced knowledge and ability to treat patients in these categories in the Netherlands. The hospital is also well known in Europe. Because of this specialization, patients travel through the entire country to receive a treatment at one of the three locations. The Sint Maartens Clinic has two executive board members and a supervisory committee. The capacity comprises 253 beds and approximately 1730 people. I conducted an interview with mr. dr. Mark van Houdenhoven, who is the board president of the Sint Maartens Clinic.

The Need for Medical Technologies

The hospital has three types of technology investments, which are investments in operation room technology, diagnostic technology and IT systems. In one way the investments in technology can improve the efficiency and decrease costs considerably at the same time. From this perspective, technology investments matter much. On the other hand we spend on average €800.000 each year on the category diagnostic technology, which is a relatively small amount. The motivation to buy a new medical device comes from medical specialists.

Guidelines Concerning Procurement

The annual report 2014 mentions that their policy concerning technology is conform the covenant medical technology. The hospital does not have a procedure that describes which proportion of this budget should be spent on either medical devices, buildings, IT infrastructure or other assets. There is one budget available for all investments. The hospital has a special committee that evaluates investment proposals, which results in one round of yearly investments. This committee consists of a mix of people with different specialisms and backgrounds. The hospital management needs to evaluate every request. An innovative technology has certain requirements, it should either be:

1. Cost reducing and / or efficiency increasing in the form of lower need for personnel or devices that perform faster. The quality of care remains at the same level.
2. Quality improving. E.g. diagnostic devices have more features which makes them perform more accurate.
3. A combination of the two.

Business Case

"*The difficult part is to assess the additional value of a new medical device. Some studies exist on the cost-effectiveness of medical devices, however, many devices are lacking cost-effectiveness evidence. Doctors are usually the persons who advocate the idea to purchase a new technology. However, if they are not able to explain or convince the added value in the first place, we will not even start to examine whether we will invest in this particular technology*".

The hospital establishes a business case based on calculations, which are similar to organizations in other industries. Mr. van Houdenhoven indicates that every hospital uses its own framework to base its investment decisions on. The variables that the Sint Maartens Clinic includes in its calculations are various. Examples are the costs of extra personnel, cost savings, how many additional patients the hospital will attract with this device, costs of extra IT implementations, the maintenance costs, costs of disposals and so on. "*We try to estimate the value of the investment as accurate as possible*".

The hospital also tries to assess the value of factors which are difficult to quantify. The additional value to the hospital of for instance, an extra precise scan device, remains uncertain. "*Some studies exist on the cost-effectiveness of medical devices, however, many devices are lacking cost-effectiveness evidence*". Regardless the uncertainty, in the end the outcome of the calculation should be compared to a certain standard which is acceptable to the hospital.

A hospital not only needs to weigh the cost-effectiveness of a single technology, but has multiple investments decisions to make, under a restricted budget. Mr. van Houdenhoven indicates that general hospitals offer a wide range of services, which means that their choice in which service line to invest is even harder. It is less complicated at a categorical hospital like the Sint Maartenskliniek. In case of uncertainty on the outcome of an investment, the hospital decides based on strategic goals, return on investment and the current state of the technology at a service line.

"*Physicians will always try to convince the management of the additional value of a certain technology. The question is whether the management is resistant to the pressure from the physicians. Hospital management has less information than medical specialists, but medical specialists also have less information than the technology supplier. There is a constant pressure which causes a technology push in hospitals to buy more advanced technologies. It is a very political process"*.

Evaluation of Medical Technologies

The hospital evaluates every case differently. Return on investment is definitely considered, but there is no guideline. The hospital has an investment committee, where the medical specialists can express their learnings and opinion in the use of the technology. The committee takes this into account when making their next investment decision. However, according to mr. van Houdenhoven, the evaluation of medical technology is very difficult. In order to evaluate the technologies properly the hospital should measure the outcomes using both the former method and the new technology. Even in the case of a difference in outcome, it is hard to establish whether it is significant. This raises a dilemma for hospital management: when was the purchase of a technology not worth it? Even if it is economically obviously not worth the investment, from a perspective of providing the best health care it might be valuable.

"*What happens in hospitals is that we 'overshoot'. Hospitals purchase devices that are used only once a year. For example in the case of the Da Vinci Robot: this is a robot that enables surgeons to perform surgeries with more precision and accuracy. The device was originally invented to perform heart surgery and the investment is €1 mln. Unfortunately the heart surgeons did not appreciate the device after all, which led to the supplier to indicate the robots' worth in the use of prostate cancer surgeries. Currently 15 hospitals in the Netherlands own a Da Vinci robot. There exist solely two articles on the evaluation of the Da Vinci robot but their results are inconclusive. Moreover, the robot requires some experience in order to use it correctly, which is estimated at 500 surgeries each year. The number of prostate cancer surgeries in the Netherlands is only 800 each year and is performed across different hospitals. This implies that physicians in the Netherlands did not gain enough experience to use the robot optimally. Conclusion: the investment was both very expensive and did not improve the health of patients significantly*".

Performance Indicators

The hospital makes no distinction between performance indicators, according to mr. van Houdenhoven. However, the hospital published in 2014 for the first time a report called 'MaartensFacts', which includes performance measurements of quality outputs. The hospital states it would like to diverge the current focus on process indicators to indicators of quality and benefits to the patient. Factors that contribute to a better performance of technology are learnings effects, maintenance, user friendliness, adaptation to the IT infrastructure and the frequency of use of the technology.

6.4 Cross-Case Conclusions

This section presents the cross-case findings and discusses these. Table five provides a summary of the case descriptions.

	Ikazia Hospital	**Havenziekenhuis**	**Sint Maartens Clinic**
Organizational context	General (48 types of care), with focus on several policlinics.	General (23 types of care), with focus on several policlinics.	Specialized in posture and movement.
Need for technology	Motivated by medical staff. Large general hospital, which needs both proven and innovative technologies.	Motivated by medical staff. Works with proven technologies that need to profitable.	Motivated by medical staff. Is a market leader which means it needs to stay competitive, also with technology.
Procurement guidelines	Conform covenant MT. Multiple internal controls.	Conform covenant MT. Multiple internal controls.	Conform covenant MT. Multiple internal controls.
Business case	Evaluates all factors attributable to the technology itself, specifically based on safety and quality.	Comprehensive. Makes forecasts and bases decisions mainly on safety. Cost-effectiveness is important for innovative investments.	Comprehensive. Tries to quantify every variable and makes forecasts.
Evaluation of technology	Future goal to introduce evaluation program.	Evaluates on an accumulated level, not per technology.	Different evaluation for every technology. Medical staff reports satisfaction about technology to investment committee.
Performance indicators	No distinction, follows IGZ. States that logistics, safety and attention to patient are lead indicators.	No distinction, follows IGZ. Wellbeing of the patient, quality and safety measures are most important.	No distinction. Published performance indicators about quality by case-mix.

Table 5. Cross-case conclusions

General findings

The hospitals differ in their organizational purpose. The Sint Maartens Clinic is different because it has only a few specializations and is a market leader in its own category. The Ikazia hospital is a large general hospital with 48 types of health care, while the Havenziekenhuis provides 23 types of health care. The latter is a subsidiary of the Erasmus MC and therefore employs a different strategy, which results in a focus on profitable and proven technologies. Every hospital indicates that the motivation to invest in technology comes from the medical specialists. The

procurement procedure is according to the covenant medical technology, which also means that every hospital has an investment committee. Before the investment is performed, several parties need to give their approval.

Business case

The business case that a hospital makes is important, because it determines in which technologies a hospital invests. Mas and Seinfeld (2008) found that hospitals procure less technologies in the case of managed care. This means that cost-control mechanisms can influence the way that hospitals behave. Both the Ikazia hospital and the Havenziekenhuis indicated that pressure to think more economically recently increased. The Havenziekenhuis addressed this to the enhanced bargaining power of health insurance companies. Furthermore, the covenant medical technology was established only a few years ago. Besides the differences in calculations, the hospitals correspond in the effort they put in further improving the business case. However, the interviews show that the business cases differ per hospital. The Sint Maartens Clinic and the Havenziekenhuis not only include specifications, but also possible cost savings, forecasts of patient visits and patient data. In case of choosing between options due to a budget constraint, hospitals indicate to base their decision on different factors. The Ikazia hospital and Havenziekenhuis value safety the most, while the Sint Maartens clinic indicates that cost-effectiveness is just as important.

Evaluation of technology

Neither one of the hospitals exerts a standard procedure of technology evaluation yet. The Havenziekenhuis evaluates only on an accumulated level, the Ikazia hospital has no evaluation program so far and the Sint Maartsen clinic only evaluates to a certain extent. However, because of the lack in clinical evidence, health workers frequently have to work with devices of which the manufacturers require suggestions for improvement (Kirisits and Ken Redekop, 2013). The Sint Maartens clinic also indicates that clinical evidence is scarce when procuring a new device. It suggests that evaluation would be useful to hospitals. The Ikazia hospital indicates that the increased usefulness of provided information improves the procurement of useful technologies, instead of technologies with a low frequency of use.

Performance indicators

Similar to the theory of nonprofit firms and what I discussed in the literature review, the hospitals cannot make a distinction between different performance indicators. Every hospital seems to value the indicators of quality outputs the most.

The aim of the case descriptions is to provide more insight in the link between medical technology and hospital performance. The information from the cases shows that hospitals exert an extensive procedure before investing in innovative technologies. The procedures differ slightly between hospitals, but multiple parties need to approve the substantive business case. Not every hospital tries to include every possible variable that can affect hospital output yet. Some degree of uncertainty will always persist, but the procedure shows the attempt to diminish information asymmetry between hospital management and medical specialists. The lack of technology evaluations shows that uncertainty concerning the performance of the technologies persists, at least among these three hospitals. Furthermore, the variety of performance indicators seems to affirm the theory of nonprofit firms. The three hospitals indicate that especially education and learning effects are important in the performance of technologies.

These cases are not representative for the entire Dutch hospital industry. Therefore, these results present no general conclusions. However, it contributes to explaining the results of the quantitative analysis.

7. Regression Results

The chapter begins with the descriptive statistics of the data sample. Paragraph 7.2 continues with the regression analysis and provides answers to hypothesis testing, while section 7.3 presents an additional test.

7.1 Descriptive Statistics

The data sample consists of 107 general and categorical hospitals measured during the years 2011 – 2014, with a total of 428 hospital-year observations. After eliminating the observations with missing variables there are 357 hospital-year observations left. Of this final sample 76 are general hospitals and 13 categorical, 37% is located in an urban area.

Table six presents the descriptive statistics per year for the continues dependent variables. Average length of stay (*LOS*) slightly increasing during the period, but shows relatively no large

changes. The number of discharges however experiences a peak especially in 2013. The number of unclosed DBC's changes lots as well. This number is calculated as the number of opened DBC's in a certain year, minus the amount of closed DBC's at fiscal yearend. Unfortunately the number of people with at least one closed DBC's is only available during 2012 – 2014. Profit stays relatively constant, while the operating costs show a decreasing trend. The solvability on the other hand improves during the period. Readmission rate suddenly increases in 2014. The models include year fixed effects which control for exogenous changes attributable to a certain year.

Mean of Dependent Variables				
Year	*2011*	*2012*	*2013*	*2014*
LOS	4.684	4.754	4.710	4.839
Discharges	157,460	146,345	195,677	163,567
Nonclosed_DBC	8,727	40,939	12,657	6867
Min_closed_DBC	-	87,190	95,051	90,383
Profit	€3,122,885	€3,434,996	€3,971,001	€3,309,369
SOLV	17.48%	19.01%	22.04%	23.40%
Oper_costs	€175,055,913	€172,497,706	€154,386,621	€147,681,350
Readmission rate	1.932	1.776	1.750	1.981

Table 6. Descriptive statistics dependent variables

Mean of Independent Variables				
Year	*2011*	*2012*	*2013*	*2014*
Techinv	€8,819,938	€11,126,186	€12,579,604	€12,223,820
Absenteeism	4.61	4.42	4.26	4.24
Beds	432	418	404	396
Med_fte	114.46	117.39	118.08	119.41
HHI_ic	2.92	2.96	2.91	2.87
Bsegment	23.94%	73.90%	64.71%	85.84%
Perf_rev	41.39%	61.49%	72.89%	74.23%
Remun_fte	€63,353	€65,054	€67,619	€68,783
Mfte_1000p	0.2743	0.2755	0.2797	0.2787
Profit_t-1	€3,145,093	€3,122,885	€3,434,996	€3,971,001

Table 7.Descriptive statistics independent variables

Table seven presents the descriptive statistics per year for the continuous independent variable and control variables. Technology investments increased during 2010 – 2012. This may indicate that technology became more important to hospitals in this period. Considering capacity, the number of beds decreased steadily, while the number of medical fte increased during the observed period. However, the number of medical specialists per person did not fluctuate much, which means that the population also increased. As expected the amounts of treatments under the B-segment increased heavily, which means that bargaining power of insurance companies increased as well. *HHI_ic* however stays quite similar. Furthermore, every hospital has a governance code, a client counsel and a supervisory committee to ensure good governance (not shown in table seven). The proxy for governance *perf_rev* indicates that the number of medical specialists that received a performance review increased during 2011 to 2014.

The problem with variables that contain large numbers is that these variables often do not meet the requirement of normality. Large absolute difference lead to skewedness. Therefore I create a logarithmic version of the variables containing large numbers. This improves the predictive power of the model, because it corrects for the skewedness. Figure three visualizes the improvement of the distribution of the variable TECHinvt-1, transformed to ln_TECHinvt-1. The right figure is the distribution after the change to a logarithm.

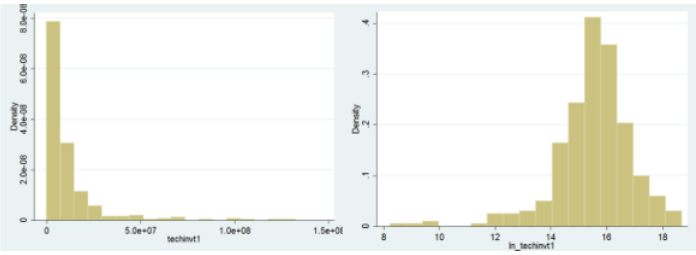

Figure 3. visualization of change to logarithm

Furthermore, table 13 in the appendix presents the Pearson correlations. Most correlations are rather low. However, *beds* and *oper_costs* are quite highly correlated with 0.78, which indicates that when the number of beds is high, so are the operational costs. The *med_fte* is highly correlated with *beds* as well, which is straightforward because they both control for size.

7.2 Regression Analysis

7.2.1 Testing of hypothesis 1: investments in medical technologies have a positive influence on the process of Dutch hospitals.

The null hypothesis states that there is not a positive association between investments in medical technology and the process of providing health care in Dutch hospitals. I test the hypothesis using a panel data random effects model, indicated by the Hausman test. The dependent variables are the number of discharges, average length of stay in days, the number of unclosed DBC's and the number of patients with at least one closed DBC. A positive coefficient for the first and fourth independent variable would indicate that investments in medical technology contribute to a more efficient process. For the other two variables, the situation is reversed. All the confounding factors are included as discussed in the model specification. The independent variables are jointly significant. The model is conducted by the panel variable hospital code and the time variable year.

	LOS		**ln_discharges**		**ln_nonclosed_DBC**		**ln_min_closed_DBC**	
	Coefficient	*SE*	*Coefficient*	*SE*	*Coefficient*	*SE*	*Coefficient*	*SE*
ln_techinvt1	**-0.009**	(0.063)	**0.103****	(0.049)	**0.100**	(0.136)	**0.124****	(0.057)
i.gen_hosp	**-0.672**	(0.813)	**0.823****	(0.034)	**0.241**	(0.672)	**1.375****	(0.631)
Beds	**0.000**	(0.000)	**0.000****	(0.068)	**0.001**	(0.001)	**0.001*****	(0.001)
Mfte_1000p	**-0.073**	(0.207)	**-0.189**	(0.207)	**-0.120**	(0.596)	**-0.248**	(0.268)
i.urb_dum	**0.000**	(0.001)	**-0.077**	(0.069)	**0.062**	(0.289)	**-0.036**	(0.001)
Med_fte	**0.216**	(0.201)	**0.002****	(0.001)	**-0.000**	(0.003)	**0.001**	(0.001)
Nr_comp								
2	**0.422**	(0.271)	**-0.269****	(0.141)	**0.385**	(0.322)	**-0.228**	(0.256)
3	**0.435**	(0.267)	**-0.362****	(0.152)	**-0.108**	(0.410)	**-0.801****	(0.314)
4	**0.409**	(0.351)	**-0.168**	(0.141)	**-0.572**	(0.377)	**-0.408**	(0.270)
5	**0.241**	(0.305)	**-0.190**	(0.224)	**-1.008**	(0.499)	**-0.352**	(0.304)
6	**-2.63*****	(0.913)	**-0.362**	(0.305)	Omitted		**0.805**	(0.705)
7	**0.478**	(0.354)	**-0.228**	(0.177)	**0.117**	(0.517)	**-0.466**	(0.347)
8	**0.200**	(0.339)	**-0.001**	(0.000)	**0.676**	(0.471)	**-0.239**	(0.248)
HHI_ic	**0.070**	(0.105)	**-0.126*****	(0.043)	**0.107**	(0.161)	**-0.249****	(0.106)
ln_bsegment	**0.187**	(0.225)	**0.372*****	(0.125)	**0.535*****	(0.129)	**0.215****	(0.110)
Absenteeism	**-0.110**	(0.100)	**-0.006**	(0.028)	**-0.122**	(0.176)	**-0.043**	(0.040)
ln_remun	**-0.053**	(0.223)	**-0.062**	(0.078)	**0.451**	(0.320)	**0.180**	(0.148)
Perf_rev	**-0.200**	(0.003)	**0.000**	(0.000)	**0.005**	(0.004)	**0.002****	(0.001)
Year								
2012	**-0.056**	(0.227)	**-0.486*****	(0.145)	**1.349*****	(0.336)	omitted	
2013	**-0.087**	(0.285)	**-0.356****	(0.146)	**-0.114**	(0.377)	**-0.035**	(0.057)
2014	**-0.059**	(0.256)	**-0.454*****	(0.146)	**0.064**	(0.449)	**-0.044**	(0.057)
constant	5.891**		6.352		4.662		3.899	
No. observations	302		287		170		196	
R^2	0.093		0.851		0.566		0.767	

***coefficient is significant at α<=0.001 ** coefficient is significant at α<=0.05 *coefficient is significant at α<=0.10. Standard errors are robust standard errors.

Table 8. Multivariate regression analysis model 1

Table eight presents the results of the first model. The left column indicates the independent variables in the model, SE stands for Standard Error. The table presents four different estimations of model one. Observing the results, one can see that technology investments are only significant for the number of discharges (*ln_discharges*) and the number of patients with minimal one closed DBC (*ln_min_closed_DBC*). It seems that technology is not associated with the average length of stay (*LOS*) or the number of DBC's that are not closed within a year (*ln_nonclosed_DBC*). Except for *LOS* are all independent variables transformed into a logarithmic form, which has consequences for the interpretation of the coefficients. For instance, if a hospital increases the amount of technology investments with one percent, the amount of discharges increases with 0.103% and the number of patients with at least one finished DBC increases with 0.124%, ceteris paribus. This indicates that investments in medical technology have a positive association with the productivity of a hospital. It is however interesting that technology seems to increase the number of discharges, but has no effect on the amount of unfinished DBC's. This could imply that productivity increased in terms of people working more efficiently, but that the amount of patients increased more rapidly. The results seem to hold specifically for general hospitals. Other important control variables that influence this relation are the number of beds and medical specialists, the number of competitors and bargaining power of the insurance companies. The effect of capacity (*beds* & *med_fte*) may be significant, but is almost zero. Competition relates to decrease the quality of the process. The concentration of health insurance companies is negatively related to the process, while the amount of DBC's in the B-segment show a positive association. Considering the testing of the hypothesis: I accept H1 that investments in medical technology are positively associated with the process in Dutch hospitals. However with the remark that the results are ambiguous.

7.2.2 Testing of hypothesis 2: investments in medical technologies are positively associated with financial performance of Dutch hospitals.

The null hypothesis states that there is not a positive association between investments in medical technology and financial performance in Dutch hospitals. The dependent variables are profit, solvability and operating costs. I test the hypothesis using a panel data with both a random effects and a fixed effects model. The Hausman test indicated that a fixed effects model would be more suitable for regressing on profit.

	Ln_profit		**SOLV**		**Ln_oper_costs**	
	Coefficient	*SE*	*Coefficient*	*SE*	*Coefficient*	*SE*
ln_techinvt1	**-0.159***	(0.093)	**-0.011****	(0.004)	**0.020*****	(0.008)
i.gen_hosp	omitted		**-0.164****	(0.063)	**1.189*****	(0.365)
Beds	**0.001**	(0.011)	**0.000**	(0.000)	**0.001*****	(0.000)
i.urb_dum	omitted		**-0.010**	(0.023)	**0.097**	(0.129)
Med_fte	**0.001**	(0.005)	**0.000**	(0.000)	**-0.002*****	(0.000)
Nr_comp	omitted					
2			**-0.061****	(0.029)	**0.238****	(0.121)
3			**0.031**	(0.029)	**-0.225**	(0.189)
4			**-0.004**	(0.031)	**0.649**	(0.141)
5			**-0.025**	(0.022)	**0.022**	(0.216)
6			**0.141**	(0.091)	**-0.972**	(0.361)
7			**0.005**	(0.031)	**-0.184**	(0.188)
8			**-0.033**	(0.022)	**-0.017**	(0.003)
HHI_ic	**-0.089**	(0.505)	**0.025**	(0.016)	**-0.036**	(0.026)
ln_bsegment	**0.286*****	(0.106)	**-0.006**	(0.007)	**0.021**	(0.014)
Absenteeism	**0.086**	(0.098)	**-0.004**	(0.005)	**-0.007**	(0.006)
ln_remun	**-0.053**	(0.223)	**-0.006**	(0.002)	**0.357*****	(0.006)
Perf_rev	**1.043**	(1.053)	**0.000**	(0.000)	**0.000**	(0.000)
ln_profitt1	**-0.019**	(0.048)	**0.006****	(0.003)	**0.001**	(0.003)
Year						
2012	FE		**0.023****	(0.010)	**0.016**	(0.017)
2013	FE		**0.062*****	(0.014)	**0.041****	(0.020)
2014	FE		**0.080*****	(0.013)	**0.045****	(0.021)
constant	2.461		0.502		12.888	
No. observations	253		268		268	
R^2	0.133		0.497		0.655	

***coefficient is significant at α<=0.001 ** coefficient is significant at α<=0.05 *coefficient is significant at α<=0.10. Standard errors are robust standard errors.

Table 9. Multivariate regression analysis model 2

Table nine presents the results for the second hypothesis. Again, the table shows the estimates of model two which is estimated three separate times. The coefficients show a significant relation between investments in medical technology and hospital performance. However, they indicate a negative relation and not a positive. A 1% increase in technology investments is related to a 0.159% decrease in profit (*ln_profit*) and a 0.02% increase in operating costs (*ln_oper_costs*), ceteris paribus. Also, a 1% increase in technology investments decreases the solvability (*SOLV*) with 0.0001, keeping everything else constant. Therefore I do not reject H0 that technology investments are not positively related to financial performance in Dutch hospitals. Obviously it is related, but in a negative manner. Being a general hospital seems to magnify the association in the same direction. Having two competitors compared to one decreases financial performance further. Interestingly the amount of DBC's in the B-segment is quite strongly related to a higher profit. Control variables that have a somewhat obvious positive association are profit in t-1 which

increases solvability (through increasing equity in year t) and remuneration of personnel increases costs. The categorical variables *gen_hosp*, *urb_dum* and *nr_comp* are eliminated using the fixed effects method when regressing on profit. This is a consequence of the fact that the fixed effects method eliminates every time invariant factor.

7.2.3 Testing of hypothesis 3: investments in medical technologies are positively associated with quality performance in Dutch hospitals.

The null hypothesis states that there is not a positive association between investments in medical technology and quality performance in Dutch hospitals. The dependent variable is the readmission rate of a hospital. I test the hypothesis using a panel data random effects model, as indicated by the Hausman test.

	Readmissionrate	
	Coefficient	*SE*
ln_techinvt1	**-0.102**	(0.073)
i.gen_hosp	**-1.714**	(1.110)
Beds	**-0.000**	(0.000)
i.urb_dum	**-0.038**	(0.211)
Med_fte	**-0.002****	(0.001)
Nr_comp		
2	**0.319**	(0.206)
3	**0.401****	(0.192)
4	**-0.317***	(0.170)
5	**-0.038**	(0.186)
6	**-3.462*****	(1.159)
7	**0.456**	(0.290)
8	**0.100**	(0.168)
HHI_ic	**0.123**	(0.114)
ln_bsegment	**-0.139**	(0.106)
Absenteeism	**-0.169****	(0.080)
ln_remun	**0.113**	(0.214)
Perf_rev	**-0.002**	(0.002)
Year		
2012	**0.077**	(0.283)
2013	**0.064**	(0.305)
2014	**0.262**	(0.311)
constant	5.428	
No. observations	277	
R^2	0.261	

***coefficient is significant at α<=0.001
** coefficient is significant at α<=0.05
*coefficient is significant at α<=0.10.
Standard errors are robust standard errors.

Table 10. Multivariate regression analysis model 3

Table 10 presents the results of the third model. The results show that the coefficient of technology investments is negative, but insignificant. A negative relation was the contemplated direction in this case, as quality improves with a lower readmission rate. The coefficients indicate that not capital (technology), but labor is more important in reducing the readmissionrate. Every additional medical specialist fte is associated with a 0.002 lower readmission rate and one unit less absenteeism is associated with even a 0.169 decrease in readmission rate, ceteris paribus. The number of competitors also seems significant. I do not accept the H1 hypothesis of a positive relation between technology investments and quality performance in Dutch hospitals.

7.2.4 Testing of hypothesis 4: the process has a mediating role in the relation between investments in medical technologies and financial performance in Dutch hospitals.

The null hypothesis states that no mediating role of process exists in the relation between investments in medical technologies and financial hospital performance. Considering the results of the previous sections, there were direct relations between both technology and the process and technology and financial performance. As explained in the methodology, the mediating effect is estimated by a bootstrapping method. It declines the number of observations, but increases the reliability through replicating the estimation 5000 times.

	Profit		**SOLV**		**Oper_costs**	
	Coefficient	*SE*	*Coefficient*	*SE*	*Coefficient*	*SE*
Ind (ln_discharges)	**0.190**	(0.161)	**-0.011**	(0.012)	**0.063**	(0.089)
Ind (ln_min_closed_DBC)	**-0.026**	(0.171)	**-0.128**	(0.013)	**0.220****	(0.089)
Ind (LOS)	**-0.002**	(0.013)	**-0.001**	(0.002)	**-0.008**	(0.010)
Ind (ln_nonclosed_DBC)	**0.022**	(0.030)	**-0.003**	(0.003)	**0.011**	(0.009)
Ind (total)	**0.183****	(0.080)	**-0.022****	(0.010)	**0.284*****	(0.052)
No. observations	116		131		131	
No. replications	5000		5000		5000	

***coefficient is significant at α<=0.001 ** coefficient is significant at α<=0.05 *coefficient is significant at α<=0.10.

Table 11. Bootstrapping model hypothesis 4

Table 11 presents the results for hypothesis four. The left column represents the independent variables of the model, where 'Ind' stands for indirect relation. The model estimates both individual indirect effects and a total indirect effect of medical technology through the process indicators, on financial performance. The coefficients show that there is an indirect total effect for each financial indicator. This implies that investments in technology are indirectly related to financial performance and that the process as a whole has a mediating role. For example,

investments in technology influence the process, which is related to an increase in profit. This is a positive effect of technology investments. This is remarkable, because the direct effect indicates a negative influence on profit, while the indirect effect increases profit. On the other hand, technology investments are related to a decrease in solvability and an increase in operating costs. Medical technology is even associated with higher operating costs, solely through the number of persons with minimal one closed DBC. The direction of the coefficients for *SOLV* and *oper_costs* are in line with the results of section 7.2.2. I accept H4 that the process has a mediating role in the relation between technology investments and financial hospital performance.

7.2.5 Testing of hypothesis 5: the process has a mediating role in the relation between investments in medical technologies and quality performance in Dutch hospitals.

The null hypothesis states that no mediating role of process exists in the relation between investments in medical technologies and quality hospital performance. The results of testing hypothesis three indicated that medical technology is not directly associated with quality of output. However, the theoretical framework gives reason to believe an indirect association does exist.

	Readmission Rate	
	Coefficient	*SE*
Ind (ln_discharges)	**-0.086**	(0.106)
Ind (ln_min_closed_DBC)	**-0.165****	(0.099)
Ind (LOS)	**-0.003**	(0.008)
Ind (ln_nonclosed_DBC)	**0.003**	(0.012)
Ind (total)	**-0.249****	(0.102)
No. observations	129	
No. replications	5000	

***coefficient is significant at α<=0.001 ** coefficient is significant at α<=0.05 *coefficient is significant at α<=0.10.

Table 12. Bootstrapping model hypothesis 5

Table 12 presents the estimation for hypothesis five. The results show that in contrast to hypothesis three, medical technology is indirectly associated with quality performance through the process. The indirect effect is visible for both the total process and the individual indicator *min_closed_DBC*; persons with minimal one closed DBC. The total effect can be interpreted as when technology investments increase with 1%, it is associated with a 0.00249 decrease in readmission rate, through the process, ceteris paribus. It means that the technology most likely influences a more productive process, which in turn positively affects the quality of health care

provided. The latter is reflected in a lower readmission rate. Therefore I accept hypothesis five that the process has a mediating role in the relation between technology investments and quality hospital performance.

7.3 Summary of the Main Findings

This chapter quantitatively examines the relation between medical technology and several measures of hospital performance. Specifically, I observe this effect for the variables average length of stay, number of discharges and unfinished DBC's, the number of persons with minimal one finished DBC, profit, solvability, operating costs and the readmission rate. Medical technology is specified as the amount of investments in machines, IT systems and other devices, for the year t-1.

The theoretical framework led to the development of five hypotheses, which are tested by using longitudinal data regression methods. The regression results indicated the following:

1) Medical technology positively relates to process quality, however not for all indicators of the process. (Accept H1)
2) Medical technology negatively relates to financial performance, which means that hypothesis two is not accepted. (Reject H2)
3) Medical technology is unrelated to quality performance. (Reject H3)
4) The process is a mediator in the relation between medical technology and financial performance. (Accept H4)
5) The process is also a mediator in the association between medical technology and quality performance. (Accept H5).

Investments in medical technology are positively related to the number of discharges and the number of persons with minimal one closed DBC, which confirms hypothesis one. However, the coefficients are insignificant for the dependent variables average length of stay and number of unfinished DBC's. The results for hypothesis two are very significant, but technology influences every financial indicator negatively. The statistical analysis shows that the medical technology coefficient is insignificant with respect to the readmission rate. This implies the rejection of H3 of a direct relation between technology and quality of output. Process plays indeed a mediating role in the relation between medical technology and both financial and quality outputs.

8. Conclusion and Discussion

This study has as objective to examine the association between medical technology and hospital performance. The next chapter answers the main research question in paragraph 8.1 in a conclusion and a discusses the results in section 8.2. Furthermore, it discusses the limitations and provides policy implications and suggestions for future research in the final two sections.

8.1 Conclusion

This thesis examines the main research question *what is the effect of investments in medical technology on the performance of Dutch hospitals?*

Through the development of an extensive theoretical model, which led to several hypotheses, and the statistical analysis using longitudinal data, I am able to answer this question. First, an effect of investments in medical technology on hospital performance does exist. Seconds, medical technology has both an indirect and direct effect on performance and the effect is both negative and positive, depending on the performance indicator. Investments in medical technology influence two out of four process indicators positively, which means that investments in technology increase the productivity and efficiency of Dutch hospitals. Investments in medical technology however decrease the financial performance of Dutch hospitals and have no effect on the quality performance. Investments in hospital technology do have a positive effect on quality through the process. Hence, an indirect positive relation exists between technology and quality performance. The results show an indirect relation for financial performance as well. Investments in technology negatively influences two out of three indicators of financial performance through the process. Therefore I conclude that investments in medical technology have a positive influence on nonfinancial performance of Dutch hospitals, but a negative effect on financial performance of Dutch hospitals.

8.2 Discussion of the Results

The results of the first hypothesis indicate that the association between medical technology and the hospital process is positive. This is similar to the expectations, hence the null hypothesis is rejected. Blank and van Hulst (2008) also found a positive relation between technology and productivity in the form of the number of discharges. However, this thesis only finds evidence for two of the four process indicators, namely number of discharges and the number of persons with

minimal one closed DBC. For average length of stay and the number of unfinished DBC's the effect is insignificant. It is remarkable that the number of discharges increases, while the number of unfinished DBC's does not decline. This may imply that productivity increased in terms of people working more efficiently, but that the amount of patients increased faster. When the diagnosis rate increases after adoption of a new technology, which leads to more treated patients than before the adoption of the technology, it is called the 'treatment expansion' effect (Pomp and Vuijc, 2008). It is uncertain whether this is the case, but it would be an interesting subject for further research. The case studies indicate that when hospitals wish to procure a new technology, they evaluate several indicators in their business case. Two out of three hospitals also forecast the amount of expected patients. The amount of patients is incorporated in the process indicators. Furthermore, every hospital is aware of the learning effects and importance of experience, which should increase the effectiveness of medical technologies. When a hospital invests in a technology, it also invest in education. These factors presumably contribute to the positive effect of technology investments on the process in Dutch hospitals.

The results of hypothesis two are interesting as well, because the estimates indicate a significant relation but in the opposite direction of what was expected. It indicates that medical technology is negatively related to financial performance in the form of profit, solvability and operating costs. These results are similar to the findings of Agha (2013), who found an increase in billed charges and insignificant effects on cost savings. Blank and van Hulst (2008) found an increase in costs of outpatient health care, but a decrease in inpatient costs. Other studies mainly showed a positive effect on financial performance (Borzekowski, 2002, Goldstein et al., 2002 & Li and Collier, 2000). The difference may be explained by the specification of the independent variable. I specify technology as the invested amount in machines, IT systems and other devices, while many other studies specify this variable as the index of actual technology availability (Agha, 2013, Borzekowski, 2002 & Goldstein et al., 2002). Investments probably show a higher correlation with financial indicators than actual technology numbers. Therefore, my results can provide a useful insight in the effect on financial performance, in comparison to other studies. Another explanation comes from the case studies. An investment in technology can either decrease costs and increase benefits, increase both costs and benefits or decrease both costs and benefits (Cutler and Mclellan, 2001). Hospitals make their own cost-benefit consideration (Goldstein et al., 2002). The results of the case studies indeed indicate that every hospital makes a

cost benefit analysis and that hospitals exert an extensive procedure before investing in innovative technologies. Several parties need to approve or control the business case in advance of approval. However, the procedures differ between hospitals. Not all hospitals take every possible variable that can affect hospital output into account. It can be that the cost benefit considerations of hospitals are not solid enough to predict future financial performance. Two out of three hospitals indicate that either their hospital or other hospitals sometimes invest in technologies, that hospitals afterwards turn out not to use frequently. Obviously this deteriorates the financial performance. Furthermore, the lack of evaluations among every hospital presumably also leads to more uncertainty. This uncertainty may explain the negative association between technology investments and financial performance in Dutch hospitals.

Hypothesis three expects a positive relation between medical technology and quality. The results however show no significant association between technology investments and the readmission rate. The only other paper that used readmission rate as quality output is Agha (2013), who found an insignificant effect as well. However, testing of hypothesis five confirms an indirect association of medical technology and readmission rates, via the path of hospital process. Li and Collier (2000) did not specifically test the effect of technology through the process on quality, but found that the process increases clinical quality. Apparently the investments in technology do not increase quality of output directly, which implies that the new technologies do not immediately improve treatments. Of course, it may be that the medical technology investments increase other indicators of quality, like the mortality rate. However, I did not include these indicators on purpose, because I am unable to identify the case-mix of patients. Moreover, even when case-mix is available a causal relation is hard to establish. However this does not mean that definitely no direct relation exists between investments in technology and output quality, but at least not for readmission rate. The significant results for hypothesis five imply that investments increase the productivity and efficiency in Dutch hospitals and that this increase leads to a lower readmission rate. The case study results indicate that every hospital values quality of output the most when choosing between performance indicators. Therefore the result of hypothesis three is somewhat surprising, while the results of hypothesis five make sense.

The result that technology investments are indirectly related to financial performance is in line with the findings of Li and Collier (2000). What distinguishes my results with the results of Li

and Collier is that they find a positive association. The statistical inference of this thesis shows that there is a positive indirect relation with profit, but negative indirect relation with solvability and operating costs. Meaning that technology investments increase the productivity which increases both profit and operating costs. This implies that profit rises because of a larger increase in operating revenue than in operating costs. Possibly the enlarged productivity stimulates revenue more than it stimulates costs. Future research should explain this matter.

8.3 Limitations

The data and research design that I use in this thesis contains several limitations. First, the selection sample is rather small with 357 hospital-years. The longitudinal character of the data partly compensates for the size, but the data also contained various missing variables. Although I eliminated the hospitals that provide barely any information, some hospitals still lack observations for certain variables. This results in different numbers of observations per estimated model. The most critical risk is that the lack of observations leads to altered results. However, I believe that the size of the dataset is comprehensive enough, certainly in combination with the other characteristics of the methodology.

Second, the case study provides useful information, but it also raises new questions. Most importantly, this research was unable to explain why some relations were insignificant or opposite to the expectations. The thesis concentrated on *whether* and *what* the effect is of medical technology on hospital performance. It cannot completely explain to hospital management how it should increase its performance, because the thesis provides no answer about the quality of the technology.

Third, the fact that I am unable to subtract data about the case-mix is definitely a limitation of this study. With the case-mix information I could have added the academic hospitals and more dependent variables of performance. It would have been an important control variable because the case-mix of the patients obviously influences indicators of quality, but also process and financial performance indicators.

Finally, the models contain a risk of endogeneity. Omitted variables or measurement error may cause a bias in the estimated results, because it is not possible to capture every factor of the real context. I tried to mitigate these problems as much as possible by using a good theoretical framework resulting in many control variables, panel data and several statistical tests. Because it is impossible to exclude the risk I do not claim to have established any causal relations.

8.4 Policy implications and Future Research

The results of this thesis have several policy implications for hospital administrations and other stakeholders. First, I would advise hospital managements to make a more solid cost benefit consideration. Currently, technology investments have a negative influence on financial performance. Therefore the business cases should concentrate more on the financial impact of the investment decision. Moreover, the health insurance companies can use the results of this thesis to enlarge their focus on the cost-effectiveness of new technologies. Hospitals should especially pay more attention to the expected use frequency of a certain technology.
Second, I think it would be useful to concentrate on improving the process indicators when investing in medical technologies. The statistical results indicate that technology investments are both directly related to a better process and indirectly through the process with better profitability and quality. Third, to institutions that control the quality of the health care system like the IGZ and NZA, I would advise to monitor cost-effectiveness studies profoundly. Clinical evidence should be stimulated in order to reduce information asymmetry and uncertainty for hospitals that procure innovative technologies. Furthermore, it may also be useful to think about a cost-effectiveness norm, as hospitals indicated to struggle with the budget constraint and choosing between options.

Considering future research, it would be very interesting to better observe why these associations between hospital technology and performance exist. The results of this thesis are limited to explaining which effects are present. To be truly useful to stakeholders, the underlying causal factors should be obtained. Another factor that should be included is case-mix of patients. To conduct a research explaining the relations and including case-mix, it would be useful to collect data first-hand. Meaning that the data should be collected from the hospitals, observing them more profoundly, in order to avoid the data limitations that this study experienced.

Moreover, the results of hypothesis one implies that the number of patients increases faster than the productivity of the hospital. Medical technology is namely significantly related to the number of discharges, but insignificant for the number of unfinished DBC’s. An interesting topic for future research would therefore to examine whether medical technology induces a treatment expansion effect.

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Appendix

A - Case Study Interview Questions

Interviewee	
Function interviewee	
Years in current position	
Date of interview	
Location of interview	
Duration of interview	

Define which technologies hospitals consider as useful.

- The academic literature examines different kinds of hospital technologies. It seems as if these proxies are chosen arbitrarily, probably because of data availability. This leads to the question: which hospital technologies are considered useful?

On what grounds hospitals believe a new technology will contribute to their performance.

- Does the hospital use a strict procedure for the procurement of hospital technology, and if yes, what does this look like?
- Which requirements does innovation have to meet in order to purchase it, e.g. considering cost-effectiveness?
- What business case makes a hospital in advance of making an investment decision?
- To what extent does a hospital experience pressure from the supplier and/or the insurance company in the investment decision?
- Do you think that hospitals buy more technology because of deregulation and competition? (this has been insinuated by the board members of the Maasstad hospital and AMC in 2012)

Identifying any guidelines on the procurement of technologies by hospitals.

- How does the hospital measure and evaluate the contribution of the invested technology? To what extent plays the return on investment a role?
- What is the importance of the opinion of the medical personnel in the use of the technology and its evaluation?

Define which performance indicators are important to hospitals, in particular nonfinancial indicators of performance.

- The academic literature uses different indicators to measure hospital performance, both financial and non-financial. What does the hospital consider as most important indicators?

Identifying which other factors influence the performance of hospitals.

- What is the influence of factors like the experience in using a technology and learnings effects in the effectiveness of the technology?
- Are there other factors that play a role in the effectiveness of the technology?

B - Libby Boxes

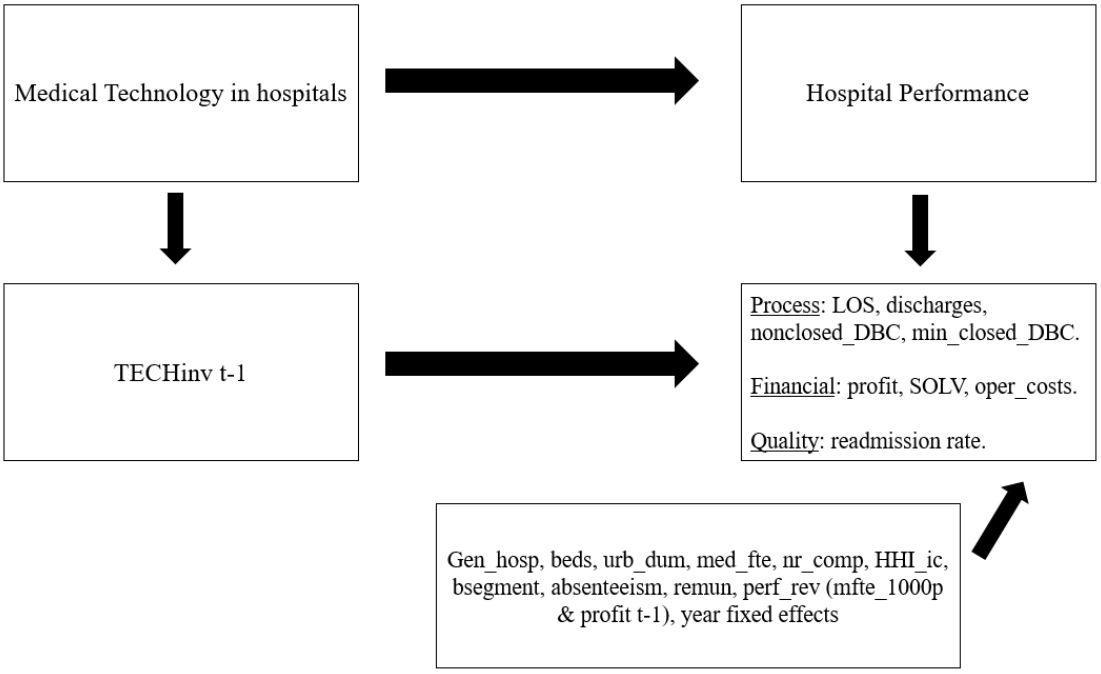

Figure 4. Libby Boxes

C - Pearson Correlations

Pearson Correlations

	Closed _dbc	*LOS*	*Nonclosed _dbc*	*Min_closed _dbc*	*Readmissionrate*	*Profit*	*SOLV*	*Oper _costs*	*Techinvt-1*	*Beds*	*Mfte_ 1000p*	*Med_fte*	*HHI_ic*	*Bsegment*	*Absenteeism*	*Remun*	*Per_rev*	*Profit _t-1*
Closed_dbc	1																	
LOS	-0.04	1																
Absenteeism	0.57	0.01	1															
Min_closed_dbc	0.91	-0,09	0.63	1														
Readmissionrate	-0.28	0.08	-0.18	-0.36	1													
Profit	0.57	0.14	0.44	0.54	0.01	1												
SOLV	-0.51	0.06	-0.12	-0.65	0.02	-0.16	1											
Oper_costs	-0.89	0.12	0.61	0.87	-0.08	0.61	-0.52	1										
Techinvt-1	0.73	0.01	0.46	0.78	-0.14	0.45	-0.5	0.77	1									
Beds	0.72	0.12	0.46	0.67	0.13	0.51	-0.28	0.78	0.63	1								
Mfte_1000p	0.4	0	0.37	0.33	-0.11	0.36	-0.12	0.4	0.31	0.34	1							
Med_fte	0.75	0.12	0.51	0.68	-0.08	0.57	-0.29	0.8	0.65	0.91	0.43	1						
HHI_ic	-0.28	0	-0.08	-0.27	0.02	-0.04	0.27	-0.24	-0.19	-0.15	0.12	-0.17	1					
Bsegment	0.54	0.09	-0.09	0.59	-0.09	0.46	-0.14	0.53	0.42	0.53	0.24	0.6	-0.11	1				
Absenteeism	0.08	-0.07	-0.07	0.11	0.01	0.1	-0.02	0.16	-0.08	-0.06	0.13	0.05	-0.15	-0.05	1			
Remun	-0.2	0.04	-0.04	-0.17	0.02	-0.1	-0.01	-0.03	0.13	-0.23	-0.11	-0.23	0.06	-0.16	0.26	1		
Per_rev	0.33	-0.06	-0.06	0.42	-0.2	0.2	-0.08	0.28	0.26	0.14	0.1	0.17	-0.18	0.27	-0.05	0.03	1	
Profit_t-1	0.39	0.13	0.13	0.31	0.02	0.45	-0.09	0.44	0.31	0.38	0.27	0.43	-0.04	0.26	0.07	-0.07	0.1	1

Table 13. Pearson correlations