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Spillover Effects of Specialization Strategies in Hospitals

An Analysis of the Effects in the Short, Medium, and Long Term

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Abstract

In most developed countries, the economic pressure on hospitals to improve their efficiency has increased considerably over the past 30 years. Simple cost reimbursement for hospital care has almost universally been superseded by much more high-powered economic incentive-based systems. These systems offer powerful incentives to reduce expenses, particularly in high-cost areas such as the operating room (OR). Specialization is one prominent response strategy to such pressures. Whether these cost-saving strategies affect later events in the patient's case or the overall costs of a case has not been investigated yet. This study tries to answer the question of whether cost-reduction efforts by specialization in the OR deploy spillover effects on non-specialized cases. If they do so, the study tries to evaluate these spillover effects on a larger scale that considers the entire patient's case, since the cost-reduction efforts may actually be counterproductive because of adverse effects in the medium to long term.

Keywords: Cost pressure, specialization, learning effects, spillover effects, follow-up costs

JEL codes: I11, M41

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1 Introduction

In most developed countries, the economic pressure on hospitals to improve their efficiency has increased considerably over the past 30 years. The once prevalent system of simple cost reimbursement for hospital care has almost universally been superseded by much more high-powered economic incentive-based systems, such as capped budget systems or Prospective Payment Systems (PPSs) (Blanchard et al., 1986; Newhouse and Byrne, 1988; Lohr, 1991; Kahn et al., 1992; Soderstrom, 1993; Simon, 1996; Eldenburg and Kallapur, 1997; Ernst and Szczesny, 2008; Cardinaels and Soderstrom, 2013). These systems offer powerful incentives to reduce expenses, particularly in high-cost areas such as the operating room (OR). Specialization is one prominent response strategy to such pressure. In other industries, strategic positioning through specialization has a long history dating back to Smith (1776), Taylor (1911) and Fayol (1918). Both the benefits (economies of scale, expert knowledge and reduced operational complexity) and drawbacks (reduced economies of scope) associated with a narrower focus are discussed in great detail in the literature, in the context of both manufacturing (e.g. Skinner, 1974; Fisher and Ittner, 1999) and services (e.g. Heskett, 1986; Huckman and Zinner, 2008). To set valuable decisions for operative and strategic questions, it is as important for hospitals as it is for every company to obtain detailed information about learning effects (e.g. Baloff, 1966; Cromwell et al., 1990; Cagir et al., 1994; Ramsay et al., 2000; Ernst and Szczesny, 2005) and the costs they influence. In the healthcare industry, Clark and Huckman (2012) examine the impact of the degree of specialization of a hospital on its clinical performance in specialized and related areas of surgery and find that greater operational focus has a positive effect on the quality of medical procedures. Ernst and Szczesny (2006) show that the learning effects in specialized cases lead to an improved resource allocation in the OR and, as a result, to lower costs. Although these studies clearly show lower expenditures in high-cost areas such as the OR, there is little evidence regarding how such isolated cost-reduction strategies affect cost developments throughout the entire patient's case.

In particular, we are interested in the question of whether cost-reduction efforts by specialization in the OR deploy spillover effects. If they do so, we have to evaluate these spillover effects on a larger scale that considers the entire patient's case, since the cost-reduction efforts may actually be counterproductive because of lower quality of surgeries as well as increased costs in the medium to long term of the patient's case for both specialized and non-specialized cases. Cost reduction strategies in an isolated area such as the OR might have negative consequences during later treatment, procedures or recovery processes. For example, consider two methods of anesthetizing a patient, where one method is much more expensive than the other one, but leads to considerably fewer problems regarding patient sickness and complications in the post-anesthesia care unit (PACU, formerly known as the recovery room). Clearly, choosing the supposedly less expensive option could lead the hospital to incur much higher costs later on and to therefore overcompensate the earlier savings. For instance, Beldi et al. (2009) study a Swiss hospital and find that hastiness in the OR leads to an increase in post-operative infections, suggesting that such a narrow focus may pose a problem in reality, as the increased follow-up costs due to post-operative infections eliminate any gains from the decreased OR costs attributable to shorter surgery time and increase overall costs per case in the end. It is thus far from obvious whether isolated cost containment measures remain beneficial in a larger perspective that considers the entire patient's case. In summary, the rarely debated issue is whether a more sophisticated specialization-based cost reduction strategy at one point in the patient's treatment process (here in the OR) with its possible spillover effects can result in higher costs at later points in the patient's case. The entire patient's case in our context denotes a patient's treatment from the surgical intervention to the treatment of possible complications in the PACU.¹

We use unique data from the healthcare industry covering one point in time, 1996, in which economic pressure on hospitals dramatically increased² and our focal hospital reacted by becoming specialized in endoprosthetic surgeries. Our data stem from a period prior to the introduction of Diagnosis-Related Groups (DRGs) in Germany and therefore allow us to study the unique situation of a hospital specialization unaffected by yearly adjustments common under the DRG system (Müller-Bergfort and Fritze, 2007). It is also unique in the sense that micro-level hospital data of similar detail to ours are virtually non-existent in Germany for the period prior to 2003/2004. We can extend previous work which has studied possible economic response strategies (Dranove, 1987; Farley and Hogan, 1990; Friedman and Farley, 1995; Ellis and McGuire, 1994; Zwanziger et al., 1996; Bailey et al., 1999; Lüngen and Lauterbach, 2002; Ernst and Szczesny, 2006, 2008; Lee et al., 2008), but has not systematically linked these strategies to effects on the entire patient's case.

We use the time from incision to suture (in the following "OR time" for short) of specialized and non-specialized interventions as an indicator of learning (specialized cases)

 $^{^1\,}$ Due to the data set, a broader definition of the patient's case is not possible. See section 5.3 for a more detailed discussion of this aspect.

 $^{^2}$ For a more detailed discussion, see section 2.

and spillover effects (non-specialized cases) which influence the short-term costs related to the OR. Our proxy for the follow-up costs of a patient's case is the probability of a patient experiencing a complication in the PACU. Because detailed micro-cost data on mediumand long-term quality are generally unavailable, we use "quality" in a short-term design to act as an indicator for costs incurred at later points in the treatment process, i.e. the short-term quality measure serves as a proxy for medium- and long-term follow-up costs. Decreasing surgery quality typically results in higher follow-up costs because of more (intensive) complications or other adverse events, a higher amount of required medication and/or the need for additional procedures and perhaps an (earlier) readmission.

The remainder of this paper is organized as follows: Section 2 presents a brief history of the German healthcare system and regulations which are relevant to our analysis. In section section 3, we discuss the impact of the reimbursement reforms on hospitals, describe possible reactions, and develop our hypotheses based on the existing literature. The data sample as well as the research model is described in section section 4, followed by the results in section 5. A discussion of the results and their limitations is presented in section section 6. The paper closes with a short summary and outlines some suggestions for further research in section 7.

2 German Health Sector and Hospital Regulations

Insurance coverage is comprehensive for every citizen and includes almost all types of inpatient and outpatient care for both emergency and elective treatments, including full pharmaceutical benefits.³ Consequently, access to high-quality healthcare is universal.

Hospital care is responsible for approximately one third⁴ of total health spending by the statutory health insurers (Bundesministerium für Gesundheit, 2018). In addition, the German hospital sector is heavily regulated. Regulatory and hospital planning authority rests with the individual German states, and any hospital that wants to treat patients insured under the statutory health insurance system has to be included in the respective state's hospital plan. Essentially, these plans are legal in nature and determine the supply

³ Some restrictions apply to experimental treatments, such as vitro fertilization, or elective plastic (cosmetic) surgery. There are also minor co-payments like 10 € per day for hospital treatment (§ 61 SGB V). The socially needy are exempt from co-payments (§ 62 SGB V).

⁴ 2016: 76, 458 mio. $€ \stackrel{\land}{=} 36.9 \%$.

side of hospital care by specifying the number of beds and the medical disciplines that may be offered by a particular plan hospital.

From 1972 until 1992, a variety of cost-reimbursement systems was used for German plan hospitals. These systems had in common that they relied on remuneration of actually incurred costs. It is therefore not particularly surprising that health insurers' expenditures for hospital care increased sharply in the late 80s and early 90s. Together with skyrocketing costs for outpatient care and especially for pharmaceutical benefits, these rising expenditures led to steadily increasing deficits for the statutory health insurers. By 1992, their combined annual deficit had almost reached 5 billion \in (Gesundheitsberichterstattung des Bundes, 2019) and hospital costs had increased by more than 9% compared to 1991 (Statistisches Bundesamt, 2019). The government then successfully secured multipartisan support for more radical reforms, which resulted in fundamental changes to hospital financing and greatly altered the underlying economic incentives. As an immediate measure, the resulting 1992 reform law⁵ introduced fixed (capped) prospective hospital budgets for the 1993–1995 period. This scheme was essentially an incremental budgeting approach that used 1991 as a budgetary baseline and limited subsequent budget increases to the annual gross increase in employee and employer health insurance contributions during the previous budgeting period. Because of its many loopholes (Simon, 1996; Busse and Riesberg, 2004; Bölt, 2007), the cost containment goals of the 1992 reform law had not been met, which led the German parliament to pass additional cost containment legislation. The 1996 act abolished all former loopholes, introduced annual budget cuts of 1%for all types of hospitals to prevent inappropriate use of hospital funds, and even denied hospitals' budget increases for higher physician and nursing wage costs resulting from collective bargaining agreements. Most healthcare experts agree that this reform law considerably increased the economic pressure of the fixed budgets. Empirical evidence supports this claim. For example, the period of capped budgets witnessed the largest decrease in average length of stay (LOS) for German hospital patients. It decreased from 13.2 days in 1992 (11.4 in 1995) to 9.2 in 2002 (Statistisches Bundesamt, 2019). Notably, this decrease exceeds the ones resulting from subsequent reforms such as the introduction of DRGs in 2003/2004. Consequently, the switch to rigidly capped budgets in 1996 offers a unique opportunity to study hospital responses. Under a capped budget regime such as 1996-2003, hospitals are comparatively free to engage in the specialization strategy that suits them best because degrees of freedom regarding these choices are comparatively

 $^{^5\,}$ Ges undheits strukturgesetz. Law for the assurance and structural improvement of the statutory health insurance.

high, which is decidedly not true under PPSs using DRGs where hospitals receive a fixed price per case depending on patient diagnoses or procedures performed. With DRGs, hospitals tend to "specialize" in certain DRGs in which perceived margins are high and ignore those in which they are low (Dranove, 1987; Schneider et al., 2008). Because DRGs are recalculated every year, former high margin DRGs frequently turn into loss makers as the result of regulatory adjustments. In short, although our data are more than twenty years old, they constitute one of the few data sets available that allow us to study hospital specialization unaffected by the system distortion associated with DRGs.

3 Background and Hypotheses

3.1 Possible Hospital Responses to Cost Containment Pressures

In the previous section, we have established that the rigidly capped budgets introduced by the 1996 reform law fundamentally altered economic incentives of hospitals. Suddenly, reimbursement has become independent of actual costs incurred and forced hospitals to closely monitor costs as well as to adopt measures to increase efficiency. Chang (2011) describes a similar problem after the introduction of global budgets in 2002 in Taiwan. The transfer of risk from the national healthcare insurance toward the hospitals forced them to focus on improving cost containment and efficiency. In this context, it has been barely investigated how hospitals' strategic responses to increased economic pressure affect different cost-related events in the patient's case. There is some work showing different strategies and the intentions behind them; for example, there is evidence that learning effects in the OR lead to improved resource allocation in the OR and thus to lower costs (e.g. Ernst and Szczesny, 2006). As far as we know, whether these cost-saving strategies affect later events in the patient's case or the overall costs of a case has not been investigated yet. Three simple examples illustrate the possible strategies found in the literature. Consider hospital A that responds to more high-powered economic incentives with a simple cost-cutting strategy, i.e. by increasing the number of patients a nurse has to care for, not replacing retiring staff or delaying the adoption of medical innovations or novel drug treatments (e.g. Brannon, 1996; Aiken et al., 2000; Sochalski, 2001; Aiken et al., 2002). Obviously, such a strategy is likely to negatively affect quality, at least in the medium to long term. Now consider hospital B that responds by reducing the number of high-risk, severely ill patients in its "patient portfolio", possibly replacing them with low-risk, less severe cases. This strategy might have been chosen because the existing literature (e.g. Baldwin et al., 2003; Chung et al., 2006) has documented a

strong positive correlation between patient risk and severity of illness on the one hand, and the resulting treatment costs on the other. Finally, hospital C may react with a more sophisticated cost-cutting strategy by identifying surgical procedures or treatment processes it performs well and then focusing on these areas. This specialization strategy may make use of standardization, learning and/or economies of scale effects in high-cost areas such as the OR. In what follows, we capture the specialization strategy and its impact on specialized and non-specialized cases, as we can examine OR data of a hospital that engaged in a specialization strategy in endoprosthetic surgery (total knee and hip replacement). This strategy was supposedly chosen by the hospital in response to cost containment pressures and was intended to be part of a viable strategy for the future. Cost reductions in the OR as a probable result of this strategy, however, cannot be treated as economically reasonable without considering the effects on the entire patient's case and therefore a more comprehensive perspective on a respective patient's case. In particular, it is not clear whether cost savings triggered by a specialization strategy and the quality performance of the hospital act as complements or substitutes (Jha et al., 2009). For example, if these more sophisticated cost-reduction activities had a negative effect on quality outcomes in the narrow focus, there might be higher follow-up costs in the patient's case, jeopardizing the initial intention of the chosen strategy.

3.2 OR Times as a Proxy for Costs

With shorter OR Times, more interventions are feasible within a given period of time, which leads to a fixed cost degression. There are also labor cost savings related to learning effects as well as a enhanced resource allocation (Ernst and Szczesny, 2006). However, shorter OR times could be a sign of lower quality which in turn could increase follow-up costs. Due to possible adverse effects of shorter OR times in the medium and long term, we also investigate the complications as an indicator for medium- and long-term follow-up costs. Only taking into consideration both indicators the OR times and the complications can we properly evaluate the economic implications of the specialization in the OR on the entire patient's case.

3.3 Complications as a Proxy for Costs

Whereas the OR times are used as an indicator for costs in the short term only, the complications serve as a medium- and long-term cost indicator. The possible effects of a specialization strategy in the OR on follow-up costs can be measured in a variety of

ways. Ideally, actual cost data are analyzed, but these data are rarely made available to researchers, particularly in one-site studies such as ours. An alternative is to use veridical proxies for costs, following Clark and Huckman's (2012) use of patient mortality in their article on hospital specialization. In our case, we employ the probability of a patient suffering from a complication in the PACU to measure the quality consequences of a specialization strategy in the OR. This quality proxy thus accomplishes two objectives. First, it can answer the question how the specialization and its effects influence short-term outcomes with regard to quality. Second, it can link these results to the follow-up costs of the patient's case.

Quality is linked to treatment costs because negative outcomes (such as complications or adverse events) are typically associated with higher resource use. There is distinct proof in the existing literature that complications are a proxy for higher costs. Kalish et al. (1995) depict an impressive increase in costs of \$16,023 if patients experienced complications. They also show that complications extend the LOS, which is consistent with the result of higher costs. In line with this, Collins et al. (1999) as well as Zhan and Miller (2003) find significant cost increases when the LOS increases. Khan et al. (2006) find a cost increase of 78% when the patient suffers from a postoperative complication after non-cardiac surgery. Dimick et al. (2004) find a cost increase of \$9,607 when a minor complication occurred and \$23,869 in case of a major one.⁶ Complications and longer LOSs are described as strong markers of resource consumption and therefore as cost drivers (Hoonhout et al., 2009). These results also have important implications for hospital costs because there is a clear positive correlation between poor quality and costs per case (e.g. Baldwin et al., 2003; Chung et al., 2006). Dimick et al. (2006) also offer support for the highly positive correlation between complications and costs. They find that reimbursement for patient care without complications exceeds hospital average costs, resulting in a profit margin of 23% for the hospital, which collapses to a mere 3.4% if complications occur. In terms of the view on the entire patient's case adopted in this paper, these authors confirm the link between complications and an increase in costs to health-care payers. In addition, the literature also claims the inverse view, i.e. that lower healthcare system costs and the quality of healthcare provided to patients are positively correlated (Veit et al., 2012; Fleming, 1991; Flood et al., 1994). For example, Jha et al. (2009) hypothesize that hospitals with lower costs may be more efficient and thus may

⁶ Nota bene: Major complications are defined as those that are considered significant enough to result in prolonged LOS or the need for additional interventions. This shows that even minor complications that do not result in a prolonged LOS lead to additional costs.

provide higher quality than hospitals with higher costs. Deily and McKay (2006) provide evidence that more cost-efficient hospitals in Florida have lower mortality rates than less efficient ones. The aforementioned literature shows that outcome quality and treatment costs can be understood as complements. Even if we assume that the immediate cost effects of these complications are unlikely to be large, we have already shown above that even minor complications (Dimick et al., 2004) may have a large impact on mediumand long-term and therefore overall costs. Other effects on prolonged LOSs, such as the patient's need for additional interventions and/or possibly readmission (Berenholtz et al., 2002; Kim and Soeken, 2005; Southern et al., 2007), support the argument that short-term quality measured by complications in the PACU can indeed be linked to mediumand long-term quality and therefore affects costs in the patient's case in a meaningful way.

3.4 Specialization and the Effect on Specialized Cases

Studies focusing on both manufacturing (Skinner, 1974; Fisher and Ittner, 1999) and services (Heskett, 1986; Huckman and Zinner, 2008) offer empirical support for the benefits of greater specialization. Applied to the healthcare industry, Hyer et al. (2009) analyze the performance of what they refer to "as a *focused hospital unit* [...]" (Hyer et al., 2009, p. 204). Clark and Huckman (2012) examine the impact of the degree of specialization of a hospital on its clinical performance in specialized and related areas of operation in the context of cardiovascular surgeries and find that greater operational focus has a positive effect on the quality of medical procedures. The existing literature supports the notion that hospitals can reduce their costs by limiting the array of services they provide (e.g. Farley and Hogan, 1990; Calem and Rizzo, 1995; Carey et al., 2008; Ernst and Szczesny, 2008; Tiwari and Heese, 2009). Consistently, Ernst and Szczesny (2006) report itensified specialization efforts of a German hospital after the capped budget systems had been introduced in 1992 and reformed in 1996. These authors especially found a learning effect occurring in the OR with respect to specialized cases, resulting in a reduction of OR times and labor costs. These results appear to support the notion that specialization strategies of hospitals have achieved their main objectives. However, it is necessary to analyze whether these isolated measures targeted at the OR impacted follow-up costs. For instance, there is some concern that shorter OR times turned the OR into a more fast-paced and therefore potentially more mistake-prone working environment. Savings made in the OR and the outcome quality of the hospital may act as conflicting objectives (i.e. substitutes). If so, this might lead to more mistakes and complications that have adverse cost consequences which may overcompensate the cost savings gained in the OR.

However, the existing literature already offers strong evidence that the higher rate of specialized surgeries together with improved allocation of resources leads to decreased complication rates and fewer mistakes in the OR (e.g. Roos et al., 1986; Dranove, 1987; Farley and Hogan, 1990; Fleming, 1991; Flood et al., 1994; Hoffmann et al., 1997; Golledge et al., 2000; Dorrance et al., 2000; Goodfellow et al., 2000; Kumar et al., 2001; Di Carlo et al., 2001; Tu et al., 2001; Barro et al., 2006; Veit et al., 2012; Clark and Huckman, 2012). Contreras et al. (2011) analyze learning effects and find strong evidence that more experienced surgical teams generate improved outcomes. Because of these references in the existing literature, our quality proxy for follow-up costs is likely to provide us with some preliminary answers to cost effects, although we do not have actual cost data available.

Based on our reasoning, and supported by the existing literature, the hypothesis regarding OR times reads:

 H_1 : Ceteris paribus, specialization in the OR leads to a decrease in the OR time for specialized interventions.

With regard to complications, as already stated, the following hypothesis results:

 H_2 : Ceteris paribus, specialization in the OR leads to a decrease in the probability of complications in the PACU for specialized interventions.

3.5 Specialization and the Effect on Non-Specialized Cases

A specialization strategy with its learning effects in the OR leads to the question whether these effects in the specialized field may not only have them for the specialized cases, but might also affect the non-specialized cases by means of spillover effects. Huesch and Sakakibara (2009) show that knowledge spillovers are a common finding in models of innovation and have been applied in health economics research in the last decade. They emphasize that based on surgeons directly interacting with team members and the daily exchange of experience, spillovers may occur pursuant to a specialization strategy. Other than that, experience gained through learning can improve processes of care, refine the standardization of procedures and policies and lead to better quality control. To put it in other words: By implementing a specialization strategy and undertaking the attendant adjustments to processes and allocation plans, a form of organizational learning might begin. Consider adjustments to the workflow made to increase surgical and process efficiency to allow for the increased numbers of specialized cases.⁷ A decreasing probability

 $^{^7}$ See table 4.

of complications for all surgeries might be a possible result of these efforts originally geared toward the endoprosthetic procedures. To measure the effects of specialization and co-specialization⁸ on quality performance, Clark and Huckman (2012) use patient in-hospital mortality rate. However, they fail to provide evidence for positive spillover effects between a hospital's focal activity and what they call related activities.⁹ Regarding our specialization actions and the higher volume of specialized cases, Com-Ruelle et al. (2008) show that outcomes can be improved by increasing activity volumes. Dudley et al. (2000) review this effect in more detail and show that mortality as the quality proxy was lower in hospitals with a greater number of elective surgeries. The translation into the specialization/quality language allows us to conclude that a specialization strategy in the OR and the gained learning experience in the specialized field, leads to efficiency gains appearing in other parts of daily work—called organizational learning or spillovers (e.g. Stata, 1989). Because the OR is a knowledge-intensive setting in which repetition and experience breed competence (Skinner, 1974), it is reasonable to assume that experience gained is likely to lead to economies of scale in shared resources (Clark and Huckman, 2012), and a spillover effect on non-specialized cases can result.

Since we assume the presence of such spillover effects, the hypotheses read:

 H_3 : Ceteris paribus, specialization in the OR leads to a decrease in the OR time for non-specialized interventions.

 H_4 : Ceteris paribus, specialization in the OR leads to a decrease in the probability of complications in the PACU for non-specialized interventions.

4 Data and Estimation Models

4.1 Information on the Data

In our analysis, we use the same anonymous data set as Ernst and Szczesny (2008). The data stem from the anesthesiology department of a small German hospital that provides basic care and keeps its patients in approximately 100 beds. For the entire study period, the hospital was community-owned by the county and operated as a not-for-profit entity.

 $^{^{8}\,}$ Medical fields near to the field of specialization.

⁹ Nota bene: The authors define positive spillovers as the extent to which a co-specialization in areas related to the cardiovascular procedures directly influences quality performance on cardiovascular patients. Areas related to cardiovascular procedures are identified by focusing on secondary diagnoses of primary cardiovascular patients being named in a sufficient number of cases (20%).

This type of detailed German micro-level hospital data from a period prior to the introduction of DRGs in Germany (2003/2004) is virtually non-existent and allows us to study a specialization strategy unaffected by the yearly adjustments that are common under the DRG system. Previous research has documented that our hospital had pursued a specialization strategy in endoprosthetic surgeries in response to the 1996 reimbursement reform, i.e. the introduction of tightened capped budgets (Ernst and Szczesny, 2008). Our data set contains information on a short-term measure of outcome quality: the occurrence of complications in the PACU. Complications are documented beginning in 1994, which allows us to examine the period from 1994 to 1998, which contains the period with the biggest increase in the specialization (1996-1998). We use 6,491 observations to examine the effects of the specialization strategy.¹⁰

The total number of cases per year fluctuates around 1,300 with the number of specialized interventions greatly increasing from 241 (around 18%) in 1994 to 431 (36%) in 1998. We see a major shift from non-endoprosthetic to endoprosthetic surgeries from 1996 to 1997. While the number of endoprosthetic interventions is sharply rising from 277 in 1996 to 364 in 1997, there is a strong decline in the number of non-endoprosthetic ones from 1,116 to 851 over the same period. We regard this shift as the result of the specialization strategy. In the years following our study period, the number of non-endoprosthetic surgeries stabilizes at around 1,200 (around 70%) per year. It is worth mentioning that the absolute number of surgeries considerably rises, reaching a maximum of 569 endoprosthetic procedures in 2001 and 2002. This second increase is thus not realized at the expense of non-specialized surgeries, but by cashing in on the investment in the specialization strategy, leading to a higher number of specialized interventions, a higher degree of capacity utilization and a enhanced fixed costs degression.

4.2 Estimation Models – OR Times

For the reason of the present study, the following regression model, trying to explain the OR times of the non-endoprosthetic ORs (ORT $_\overline{ENDO}$), was set up:¹¹

¹⁰ Table 4 shows the descriptive statistics for all relevant variables.

 $^{^{11}\,\}mathrm{See}$ table 1 for a short description of all variables.

$$ORT_\overline{ENDO} = \beta_0 + \beta_1 \cdot \Sigma ORT_ENDO + \underbrace{\beta_2 \cdot \Sigma ORT_ENDO}_{+\beta_3 \cdot ASA_2 + \dots + \beta_6 \cdot ASA_5} \xrightarrow{\text{omitted}} \\ + \beta_7 \cdot BLOSS + \beta_8 \cdot OOR + \beta_9 \cdot ORW + \beta_{10} \cdot AGE \qquad (1) \\ + \beta_{11} \cdot SUR_2 + \dots + \beta_{20} \cdot SUR_{11} \\ + \beta_{21} \cdot 1995 + \dots + \beta_{24} \cdot 1998 + \varepsilon$$

In regression model 1, experience in the specialized as well as non-specialized cases is measured via cumulated OR times and used as regressors $\Sigma \text{ ORT}$ ENDO (specialized / endoprosthetic) and ΣORT ENDO (non-specialized). Because hospitals tend to have more precise information regarding expected severity than insurers, they tend to replace difficult cases with lighter cases while holding total patient numbers (capacity) stable (Ellis, 1998; Brekke et al., 2012). Since the occurrence of complications is highly correlated with the American Society of Anesthesiologists (ASA) classification of patients (e.g. Matin et al., 2003; Novara et al., 2009; Hautmann et al., 2010), a different patient portfolio has an impact on overall quality. On average, fewer patients with high severity lead to fewer complications and thus causes quality measures such as complications or mortality rates to improve (i.e. to be positively biased). To obtain meaningful results, it is therefore essential to control for the risk classification respectively the medical condition of the patients. To do so, we employ the ASA score. The literature confirms this score as a high-quality and appropriate predictor for complications and postoperative outcomes (e.g. Arvidsson et al., 1996; Hall and Hall, 1996; Wolters et al., 1996). The observation's ordinal ASA score is translated into dummy variables ASA_i (i = 1, ..., 5), which respectively represent the classification of the ASA scores (1 for a normal healthy and 5 for a moribund patient).¹² We expect the complication rate to increase with an increasing ASA score. It is reasonable to have a closer look at the mean ASA scores in (non-)endoprosthetic cases.¹³ Mean ASA scores are higher for endoprosthetic cases than for non-endoprosthetic ones in each considered year. The mean ASA score for endoprosthetic cases slightly decreases with fluctuations over time. For non-endoprosthetic cases, the mean ASA score even increases slightly with fluctuations, which explains the increase in the overall mean ASA score. To conclude, there cannot be found a tendency neither for endoprosthetic, nor for nonendoprosthetic cases. It does not seem that the hospital implemented a certain selection strategy as a reaction to increased cost pressure.

 $^{^{12}}$ For a description of the ASA scores, see table 3. ASA 1 is the reference category and therefore, ASA₁ is not included in the regression model.

 $^{^{13}}$ For the mean ASA scores, see table 4.

In addition to the ASA classification, we assume the blood loss (BLOSS) and the patient's age (AGE) as signifiers of the complexity of a case, possibly extending OR times. Although AGE does not signify complexity itself, it can be used as an instrument for various unobservable signifiers of complexity. Furthermore, we use the waiting time resulting from operating activities (ORW) as a further indicator of complexity by identifying the time required for additional unplanned actions during procedures.¹⁴ OOR is a count variable of other operations which are conducted simultaneously besides the main operation. SUR_i is a dummy variable for the i^{th} surgeon in our data set.¹⁵ Using these dummies, we can control for unobservable differences between surgeons. It may be the case that a certain surgeon is generally faster or slower than others. 1995 to 1998 are dummy variables for the invidiual years to control for potential unobserved changes over time. The term ε represents the error term.

In order to obtain more specific results, the regressor $\Sigma \text{ ORT}_\text{ENDO}$ in model 1 is replaced by $\Sigma \text{ ORT}_\text{AREA}$ in model 2, i.e. the experience in the respective OR area (abdomen, extremities, neck, head, proctology, thorax, urology)¹⁶ is used. Likewise, the OR times in the OR areas, i.e. ORT_AREA, serves as the regressand instead of ORT_ENDO. This means, the estimation has been brought from the hospital to the OR area level.

$$ORT_AREA = \beta_0 + \beta_1 \cdot \Sigma ORT_ENDO + \underline{\beta_2 \cdot \Sigma ORT_AREA} + \beta_3 \cdot ASA_2 + \dots + \beta_6 \cdot ASA_5 \qquad \text{omitted} + \beta_7 \cdot BLOSS + \beta_8 \cdot OOR + \beta_9 \cdot ORW + \beta_{10} \cdot AGE \qquad (2) + \beta_{11} \cdot SUR_2 + \dots + \beta_{20} \cdot SUR_{11} + \beta_{21} \cdot 1995 + \dots + \beta_{24} \cdot 1998 + \varepsilon$$

Since almost no dummy for an individual year has an influence significantly different from zero (in the following "significant" for short), we replace these by the dummy POST95, which signals whether an observation is from 1996 onwards (specialization period) to control for potential differences between the period before and the period of

¹⁴ For example, it includes consultations with another physician or the preparation of surgical instruments for an unexpected higher scope of a procedure.

¹⁵ The first surgeon serves as the reference category and is not included in the regression model.

 $^{^{16}}$ The OR area codes used in this paper can be found in table 2.

specialization.

$$ORT_AREA = \beta_0 + \beta_1 \cdot \Sigma ORT_ENDO + \underbrace{\beta_2 \cdot \Sigma ORT_AREA}_{+\beta_3 \cdot ASA_2 + \dots + \beta_6 \cdot ASA_5} \xrightarrow{\text{omitted}} \\ + \beta_7 \cdot BLOSS + \beta_8 \cdot OOR + \beta_9 \cdot ORW + \beta_{10} \cdot AGE \qquad (3) \\ + \beta_{11} \cdot SUR_2 + \dots + \beta_{20} \cdot SUR_{11} \\ + \beta_{21} \cdot POST95 + \varepsilon$$

However, there are problems with the regression models due to strong multicollinearity with regard to $\Sigma \text{ORT}_\text{ENDO}$ and $\Sigma \text{ORT}_\overline{\text{ENDO}}$ (model 1) as well as $\Sigma \text{ORT}_\text{AREA}$ (model 2/3). Variance Inflation Factors (VIFs) for ORT_AREA and ORT_ENDO are often above 200, indicating that there are problematically high levels of multicollinearity (Greene, 2018; Urban and Mayerl, 2008). Regressions with only one of these regressors mostly yield significant coefficients. When regressing $\Sigma \text{ORT}_\overline{\text{ENDO}}$ and $\Sigma \text{ORT}_\text{AREA}$ on $\Sigma \text{ORT}_\text{ENDO}$, it is possible to explain more than 95% of the variance of the regressand. Due to multicollinearity, the non-endoprosthetic experience therefore has to be omitted from the models.

4.3 Estimation Models – Complications

To test our hypotheses regarding the probability of a patient experiencing a complication in the PACU, we estimate different maximum likelihood models for dichotomous dependent variables (binary logit). Our models examine the influence of a set of independent variables on the probability of a complication P(COMPL).

We use the dummy variable COMPL, which reveals if there is a complication in the PACU. The regression results enable us to make statements regarding how the probability of experiencing a complication changes, if the independent variables¹⁷ in the regression model alter. Based on our assumptions and the clinical information about the various independent variables, we establish the following logit model:

$$E(COMPL \mid \boldsymbol{x}) = P(COMPL = 1 \mid \boldsymbol{x}) = \int_{-\infty}^{z} f(t)dt = \int_{-\infty}^{z} \frac{e^{-z}}{(1 + e^{-z})^2} = \frac{1}{1 + e^{-z}}$$
(4)

 $^{^{17}\,{\}rm For}$ a short description of all variables, see table 1.

$$z = \mathbf{x}' \boldsymbol{\beta} = \beta_0 + \beta_1 \cdot \text{ENDO} + \beta_2 \cdot \text{ENDOSHARE} + \beta_3 \cdot \text{ASA}_2 + \dots + \beta_6 \cdot \text{ASA}_5 + \beta_7 \cdot \text{BLOSS} + \beta_8 \cdot \text{OOR} + \beta_9 \cdot \text{ORT} + \beta_{10} \cdot \text{ORW} + \beta_{11} \cdot \text{URG} + \beta_{12} \cdot \text{AGE} + \beta_{13} \cdot \text{SUR}_2 + \dots + \beta_{22} \cdot \text{SUR}_{11} + \beta_{23} \cdot 1995 + \dots + \beta_{26} \cdot 1998$$

To depict the influence of the specialization strategy in endoprosthetic surgeries and to test our hypotheses, we use the dummy variable ENDO and the continuous variable ENDOSHARE. By indicating if the procedure is an endoprosthetic one, ENDO controls for potential quality differences between endoprosthetic and other interventions. EN-DOSHARE reflects the three-month moving average of the percentage of endoprosthetic cases.¹⁸ To represent complexity, we also use the OR time (ORT), since more complex interventions supposedly take longer. OOR is employed since it could be that the probability of a complication is higher if there were other operations conducted simultaneously. Another regressor is URG, the urgency of the OR, since we assume that the probability of a complication is larger for an emergency OR than for an elective OR planned a certain time in advance.

To be able to distinguish between potentially differing effects of the specialization strategy on specialized and non-specialized interventions, which is not possible with model 4, we additionally include the interaction term ENDO_ENDOSHARE in model 5. It reflects the interaction between ENDO and ENDOSHARE.¹⁹ By the help of the interaction term, we can split the overall effects observed in model 4 into separate effects for specialized and non-specialized procedures. We write:

$$E(COMPL | \boldsymbol{x}) = P(COMPL = 1 | \boldsymbol{x}) = \frac{1}{1 + e^{-z}}$$
(5)

 $\begin{aligned} z &= \boldsymbol{x}' \boldsymbol{\beta} = \beta_0 + \beta_1 \cdot \text{ENDO} + \beta_2 \cdot \text{ENDOSHARE} + \beta_3 \cdot \text{ENDO_ENDOSHARE} \\ &+ \beta_4 \cdot \text{ASA}_2 + \dots + \beta_7 \cdot \text{ASA}_5 \\ &+ \beta_8 \cdot \text{BLOSS} + \beta_9 \cdot \text{OOR} + \beta_{10} \cdot \text{ORT} + \beta_{11} \cdot \text{ORW} + \beta_{12} \cdot \text{URG} + \beta_{13} \cdot \text{AGE} \\ &+ \beta_{14} \cdot \text{SUR}_2 + \dots + \beta_{23} \cdot \text{SUR}_{11} \\ &+ \beta_{24} \cdot 1995 + \dots + \beta_{27} \cdot 1998 \end{aligned}$

 $^{^{18}}$ For example, it takes the value of 16.29 for an observation in March 1994 because 16.29 % of all surgeries from January to March of 1994 were endoprosthetic interventions.

¹⁹ The interaction term therefore equals 0 if it is a non-specialized procedure and ENDOSHARE if it is a specialized one.

Since the dummies for 1996, 1997, and 1998 are significant, but the dummy for 1995 (before specialization) is not,²⁰ we replace the dummies for the individual years by the dummy POST95. Therefore, the regression models are:

$$E(COMPL \mid \boldsymbol{x}) = P(COMPL = 1 \mid \boldsymbol{x}) = \frac{1}{1 + e^{-z}}$$
(6)

$$z = \mathbf{x}' \boldsymbol{\beta} = \beta_0 + \beta_1 \cdot \text{ENDO} + \beta_2 \cdot \text{ENDOSHARE} + \beta_3 \cdot \text{ASA}_2 + \dots + \beta_6 \cdot \text{ASA}_5 + \beta_7 \cdot \text{BLOSS} + \beta_8 \cdot \text{OOR} + \beta_9 \cdot \text{ORT} + \beta_{10} \cdot \text{ORW} + \beta_{11} \cdot \text{URG} + \beta_{12} \cdot \text{AGE} + \beta_{13} \cdot \text{SUR}_2 + \dots + \beta_{22} \cdot \text{SUR}_{11} + \beta_{23} \cdot \text{POST95}$$

$$E(COMPL \mid \boldsymbol{x}) = P(COMPL = 1 \mid \boldsymbol{x}) = \frac{e^{z}}{1 + e^{z}}$$
(7)
$$z = \boldsymbol{x}'\boldsymbol{\beta} = \beta_{0} + \beta_{1} \cdot ENDO + \beta_{2} \cdot ENDOSHARE + \beta_{3} \cdot ENDO_ENDOSHARE + \beta_{4} \cdot ASA_{2} + \dots + \beta_{7} \cdot ASA_{5}$$

$$+ \beta_8 \cdot \text{BLOSS} + \beta_9 \cdot \text{OOR} + \beta_{10} \cdot \text{ORT} + \beta_{11} \cdot \text{ORW} + \beta_{12} \cdot \text{URG} + \beta_{13} \cdot \text{AGE} + \beta_{14} \cdot \text{SUR}_2 + \dots + \beta_{23} \cdot \text{SUR}_{11}$$

 $+ \beta_{24} \cdot \text{POST95}$

5 Results

5.1 OR Times

Table 6 depicts the estimation results of model 1. Implied by the negative²¹ coefficient of $\Sigma \text{ORT}_\text{ENDO}$, the experience in endoprosthetic procedures reduces OR times of nonendoprosthetic surgeries. This means, there is a spillover effect from specialized to nonspecialized interventions, manifesting in shorter OR times. In the following, the estimation results of model 2 and 3 are explained which allow us to make more specific statements about the spillover effect.

Table 7 contains the estimated coefficients of model 2. The overall spillover effect on non-endoprosthetic interventions in model 1 is specified here: there is not a spillover effect on interventions in all OR areas, but extremities (EXT), proctology (PRO), and urology

 $^{^{20}\,\}mathrm{See}$ table 9.

²¹ All coefficients which are interpreted are significantly different from zero.

(URO). The result with regard to EXT is the most obvious one, since endoprosthetics is a field within EXT. But there is also a spillover effect on interventions in OR areas which are "further away" from the endoprosthetic field.

Table 8 depicts the estimation results of model 3. Similar to model 2, the experience in endoprosthetic interventions has a negative, OR time-reducing, influence on procedures in the same OR areas as for model 2 and additionally thorax (THO).²²

Regarding patient's risk classification, the results confirm our expectations. For model 1 up to 3, most coefficients of ASA_i are positive.²⁴ The absolute value of the coefficients mostly increases with an increase in the ASA score.²⁵ Thus, the results confirm that the OR time increases with an increasing patient risk classification. A rising blood loss also increases OR time, as it is with other operations executed besides the main intervention, and an increase in the patient's age. Not surprisingly, the waiting time from operating activities also extends OR time.

5.2 Complications

Table 9 depicts the estimation results of the logit models regarding the probability of experiencing complications in the PACU. Model 4 and 6 explore whether an increase in the share of specialized procedures has an effect on the complications of all interventions. The negative coefficient of ENDOSHARE (model 6) indicates that an increase in the share of specialized procedures leads to an overall decrease in the probability of experiencing complications, i.e. increased specialization leads to a decrease in complications for specialized as well as non-specialized cases. To illustrate the specialization effects numerically: An increase in ENDOSHARE by one unit (i.e. the share of endoprosthetic interventions increases by one percentage point) on average decreases the probability of experiencing complications by about 0.003357 percentage points.²⁶

The negative coefficient of ENDOSHARE (model 7) has the same indications as in model 6. The negative coefficient of ENDO_ENDOSHARE (model 7) indicates that the

²² Variance Inflation Factors (VIFs) for model 1 up to 3 are considerably below 10, indicating that there are no severe problems arising from a problematically high level of multicollinearity (Greene, 2018; Urban and Mayerl, 2008). The only exceptions are some surgeon dummies.²³

 $^{^{24}}$ Exceptions: ASA_i in ORT_HEAD and ORT_NECK (model 2, 3).

 $^{^{25}}$ Exceptions: ASA₅ (model 1), ASA₃ in ORT_EXT (model 2, 3).

²⁶ Since the marginal effect is dependent on the value of z, the average of the estimated marginal effect of the change in the j-th regressor of all observations is computed: $\frac{1}{n} \sum_{i=1}^{n} \lambda(\mathbf{x}'_i \hat{\boldsymbol{\beta}}) \cdot \hat{\beta}_j$ with λ being the logistic density function.

effects of the specialization strategy are stronger for specialized procedures compared to non-specialized ones, i.e. the complication risk is reduced more for specialized cases.²⁷ Numerically, this means: An increase in ENDOSHARE by one unit on average decreases the probability of experiencing complications by about 0.004772 percentage points for endoprosthetic and 0.00255 percentage points for non-endoprosthetic cases (0.003076 percentage points on average for all cases).²⁶ In summary, this supports H_2 and therefore, we cannot reject H_2 . This finding is in line with results from Clark and Huckman (2012), who find that greater operational focus has a positive effect on the quality performance of medical procedures.

The results regarding non-specialized cases indicate the presence of spillover effects. In summary, H_4 is supported and we therefore cannot reject H_4 . We consider this an important result because in contrast to Clark and Huckman (2012), who fail to find spillover effects, we find such effects in our data.

In model 4 and 5, the coefficients of the dummy for 1996, 1997 and 1998 are negative, as it is for the coefficient of POST95 in model 6 and 7. This finding suggests that in spite of public distrust, the increasing cost pressure caused by the introduction of rigidly capped budgets in 1996 did not lead to an increase in complications and thus to compromises on quality, at least if a specialization strategy had been implemented as an reaction. Consequently, sophisticated specialization-based cost-reduction strategies and the previously linked learning and spillover effects with regard to short-term quality appear to be strategic complements rather than substitutes.

For model 4 up to 7, all coefficients of ASA_i are positive. The absolute value of the coefficients increases markedly with an increase in the ASA score. Thus, the results confirm our expectations concerning patient's risk classification. Regarding the other control variables, we find an increasing probability of experiencing complications with an increase in the patient's age. Positive coefficients of BLOSS, ORW and ORT indicate that an increase in the amount of lost blood, the waiting time from operating activities as well as the OR time itself lead to a higher probability of complications in the PACU.

Summa summarum: We can state that the specialization has a positive effect not only for specialized cases, but also for the others due to spillover effects. Besides the OR times,

²⁷ VIFs for model 4 up to 7 are considerably below 10, indicating that there are no severe problems arising from a problematically high level of multicollinearity (Greene, 2018; Urban and Mayerl, 2008). The only exceptions are ENDO and ENDO_ENDOSHARE in model 5 and 7 with values slightly higher than 10, but they are still significant, so multicollinearity is not a major problem, as well as some surgeon dummies in model 4 to 7. The correlation matrix of the variables is also provided in table 5.

the complication rates in the PACU decrease for all interventions, indicating lower costs in the short, medium, and the long term.

5.3 Limitations

There are some limitations to our results. One must bear in mind that the complexity of the study further increases by the fact that, in reality, hospitals are likely to respond to an increase in economic incentives with a mixture of strategies and have, in fact, been shown to do so in empirical research (e.g. Ernst and Szczesny, 2005, 2006, 2008). The problem is that many effects of the respective strategies may cancel out one another, which obviously makes it even harder to predict the resulting effect on quality and costs over the entire patient's case.

Concerning the definition of the patient's case in this study. It would be reasonable that a patient's case comprises the intervention, the PACU, the intensive care unit, the ward up to the patient's discharge. If there were a readmission (e.g. due to possible complications) associated with the primary intervention, it would need to be part of the patient's case, too. However, it is not possible with the given data set to have a patient's case comprise any treatment after the PACU and we are not able to connect cases such that a case might be a readmission of a patient from a former case. Therefore, it is not clear whether a reduction of OR times (resulting from learning and spillover effects associated with the specialization strategy) leads to higher complications might, for example, show up in the ward, potentially leading to a longer LOS, and therefore higher costs (Kalish et al., 1995; Collins et al., 1999; Zhan and Miller, 2003). Unfortunately, we have not had these data available.

6 Robustness of Estimation Models

We have conducted several robustness tests on our results. We estimated model 1 to 3 with a different measurement of experience: via the sum of ORs instead of cumulated OR times. The results did not relevantly differ.

We obtain the same results when using the one-month, six-month, or nine-month moving average of the percentage of endoprosthetic cases for ENDOSHARE instead of the three-month moving average in model 6 and $7.^{28}$ Furthermore, the estimation results of model 4 to 7 virtually do not change even when the observation period is enlargened to 2002, i.e. the year prior to the introduction of the DRG system.

To control for potential differences between statutorily and privately insured patients, we included a dummy variable if the patient was privately insured in model 4 up to 7. Regarding the complications, our short-term quality measure, we find no significantly divergent results for privately and statutorily insured patients.

7 Conclusions

Since there has been the need to draw a more comprehensive view of isolated cost savings on the entire patient's case, this paper contributes to the existing literature by offering an important link between the cost savings related to learning and spillover effects in the OR triggered by a specialization strategy and the potentially higher follow-up costs which might overcompensate the savings in the OR. As we have set the focus on a specialization strategy as a reaction to upcoming cost pressure, we have assumed that specialization influences the quality of patients' outcome and therefore the follow-up costs of the respective cases.

We have hypothesized that isolated cost-reducing activities in the OR (through a specialization strategy and resulting learning and spillover effects) shorten OR times and simultaneously increase quality by lowering the probability of experiencing complications and therefore reduce the costs over the entire patient's case for both specialized (learning effects) and non-specialized cases (spillover effects). To make statements regarding how follow-up costs are affected by the specialization strategy, we have used a quality proxy.

The available data have enabled us to measure short-term quality by estimating the effects of different factors on the probability of experiencing complications in the PACU. We have found that with an increased degree of specialization, the hospital can reduce OR times and simultaneously improve short-term quality. This result applies for specialized cases (endoprosthetic surgeries) as well as for non-specialized cases. Therefore, we have concluded that increased specialization efforts and associated considerations regarding the (re-)organization of processes and procedures within the specialized area imply positive

²⁸ In contrast to the other ENDOSHARE variables, ENDOSHARE_1 (one-month moving average) does not use the month of the observation, but the previous month. Further, it is a single value and only titled "average".

spillovers on other surgeries. Based on the results of Ernst and Szczesny (2008), we have named the effects of the endoprosthetic process optimization a form of learning. These effects also show that efficiency efforts in the OR do not necessarily lead to higher followup costs after the surgical intervention. On the contrary, the hypothesis of a reduction in complications and therefore a cost reduction over the entire patient's case can be confirmed.

Our findings reveal a hint of association between learning effects in the OR triggered by the specialization strategy, resulting in efficiency gains, and higher patient volumes using economies of scale. Improved patient outcomes (i.e. lower complication rates) link these developments with overall costs over a patient's case. A strong reduction in the complication appearance for endoprosthetic as well as non-endoprosthetic cases increases the specialization effects described above. Thus, we contribute to the existing literature by showing that isolated cost-saving activities have a cost-saving effect not only in the isolated area, but also in the rest of the patient's case in the form of lower follow-up costs due to a lower complication risk. Considering our tests, these findings are robust.

Future research might obtain deeper insights in individual vs. organizational learning and spillover effects and the consequences on costs. With a larger data set, it would be possible to conduct estimations on surgeon level, which has not been done here due to mostly a low numbers of cases of a single surgeon within a specific OR area and partially also a low number of interventions in general. With a enhanced data base, future research might investigate the specialization, learning, and spillover effects in a larger perspective, defining the patient's case the way we have proposed in the introduction, i.e. a patient's case comprises the intervention, the PACU, the intensive care unit, the ward up to the patient's discharge. If there were a readmission (e.g. due to possible complications) associated with the primary intervention, it would be supposed to be part of the initial patient's case, too. With a even further enhanced data base, possibly from the health insurers, future research might investigate the effects even in a larger perspective, not restricting the patient's case to the hospital, but regarding the case from the hospital up the after-hospital care, i.e. to the point, in which the case is ultimately over from the patient's perspective, e.g. after the hospital stay and a subsequent physiotherapy. Then, research would be able to evaluate the specialization strategy from the health insurers' perspective. Linked studies should also think about a different, more concise measurement of experience in order to ease the problem with multicollinearity, to be able to better separate between experience in specialization and OR area, and to need not

to omit the experience in the respective OR area from the model. However, this would obviously require much medical expertise.

Appendix A

A.1 Description of Variables

Table 1:	Description	of	Variables	
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Variable	Description					
ORT	Operation time (time from incision to suture)					
COMPL	1 if a complication in the PACU occurs, 0 otherwise					
ENDO	1 if endoprosthetic procedure, 0 otherwise					
ENDOSHARE	Three-month moving average of the share of endoprosthetic procedures as a proportion of all cases					
ENDO_ENDOSHARE	Interaction term of ENDO and ENDOSHARE. 0 if ENDO is 0 and equal to ENDOSHARE if ENDO is 1					
$\overline{\mathrm{ASA}_i}$	Dummy for ASA class i (Classification of patients with re- gard to their physical condition. The smaller, the better the condition is.) For a description of the ASA classes, see table 3					
BLOSS	Blood Loss (measured in ml)					
OOR	Number of other operations which are done simultaneously with the main intervention					
ORW	Waiting time resulting from operating activities					
URG	Urgency of an operation $(1 = \text{elective OR}, 2 = \text{urgent OR}, 3 = \text{emergency OR})$					
AGE	Patient's age					
POST95	1 if observation is between 1996 and 1998, 0 otherwise					
$\Sigma \text{ ORT}_\text{ENDO}$	Experience in endoprosthetic area (measured as cumulated operation time in min.)					
$\Sigma \text{ ORT} \underline{\overline{\text{ENDO}}}$	Experience apart from endoprostethic area (measured as cumulated operation time in min.)					
$\Sigma \text{ORT}_\text{AREA}$	Experience in OR area (measured as cumulated operation time in min.)					

SUR _i	Dummy for the <i>i</i> -th surgeon $(i = 2,, 11)$
1995 / 1996 / 1997 / 1998	Dummy for the year 1995 / 1996 / 1997 / 1998
ε	Error term

A.2 OR Areas

Table 2: OR Areas

Abdomen
Extremities (endoprosthetic interventions excluded)
Neck
Head
Proctology
Thorax
Urology

A.3 ASA Classes

Table 3: ASA Classes (American Society of Anesthesiologists, 2019)

ASA 1	A normal healthy patient
ASA 2	A patient with mild systemic disease
ASA 3	A patient with severe systemic disease
ASA 4	A patient with severe systemic disease that is a constant threat to life
ASA 5	A moribund patient who is not expected to survive without the operation
ASA 6	A declared brain-dead patient whose organs are being removed for donor pur-
	poses

A.4 Summary Statistics of Relevant Variables

		1994	1995	1996	1997	1998	Σ
	n	300	195	296	186	152	1,129
ASA1 '	p	22.11%	14.71%	21.25%	15.31%	12.67%	17.39%
	n	560	617	681	614	591	3,063
ASA2	р	41.27%	46.53%	48.89%	50.53%	49.25%	47.19%
ΛςΛ	n	397	452	374	383	391	1,997
	р	29.26%	34.09%	26.85%	31.52%	32.58%	30.77%
	n	98	61	41	32	65	297
	р	7.22%	4.60%	2.94%	2.63%	5.42%	4.58%
	n	2	1	1	0	1	5
A0A5	p	0.15%	0.08%	0.07%	0.00%	0.08%	0.08%
$\Delta \mathbf{S} \Delta \mathbf{A}^{(1)} (i - 1 \ 2 \ 5)$	n	$1,\!357$	1,326	1,393	1,215	1,200	6,491
$ADA_i + (i = 1, 2,, 0)$	x	2.2203	2.2881	2.1170	2.2148	2.3100	2.2275
AGE	x	46.75	51.21	50.99	55.08	57.68	52.15
AGL	σ	25.6888	23.3509	23.4360	22.6586	21.4096	23.7038
OBT	x	47.41	46.87	43.97	45.88	46.50	46.11
	σ	42.3310	38.7100	37.6850	48.5631	38.4952	41.2601
ENDO	n	241	248	277	364	433	1,563
	р	17.76%	18.70%	19.89%	29.96%	36.08%	24.08%
$\overline{\text{FNDO}}^{1}$	n	$1,\!116$	1,078	1,116	851	767	4,928
	р	82.24%	81.30%	80.11%	70.04%	63.92%	75.92%
$ASA_i (ENDO)^{1}$ (i = 1, 2,, 5)	x	2.7469	2.6734	2.4657	2.4533	2.5219	2.5547
$ASA_i (\overline{ENDO})^{1)} (i = 1, 2,, 5)$	x	2.1066	2.1994	2.0305	2.1128	2.1904	2.1238
COMPL ¹⁾	n	204	225	151	87	79	746
	p	15.03%	16.97%	10.84%	7.16%	6.58%	11.49%
$COMPL (ENDO)^{1}$	n	74	66	42	33	35	250
	p	30.71%	26.61%	15.16%	9.07%	8.08 %	15.99%
$COMPL (\overline{ENDO})^{1}$	n	130	159	109	54	44	496
	p	11.65%	14.75%	9.77%	6.35%	5.74%	10.06%

 Table 4: Summary Statistics of Relevant Variables

¹⁾ Not used as regressor.

A.5 Correlation Coefficients

Table 5: Correlation Coefficients

POST95											1.0000
ENDO_ENDOSHARE										1.0000	0.2127
ENDOSHARE									1.0000	0.3464	0.6488
ΣORT_ENDO								1.0000	0.8491	0.2914	0.8163
ORW							1.0000	0.4450	0.3911	0.3325	0.3655
BLOSS						1.0000	0.1751	0.0864	0.0790	0.1691	0.0683
OOR					1.0000	0.1381	0.0502	0.0295	0.0216	-0.0930	0.0115
ENDO				1.0000	-0.1029	0.1484	0.2588	0.1533	0.1818	0.9394	0.1149
URG			1.0000	-0.1922	0.0322	0.0013	0.0396	0.1359	0.1025	-0.1829	0.1310
AGE		1.0000	0.0462	0.4096	0.0368	0.1417	0.2412	0.1476	0.1423	0.3861	0.1132
ORT	1.0000	0.3090	0.0043	0.1196	0.2694	0.3742	0.2009	-0.0112	-0.0025	0.1000	-0.0211
	ORT	AGE	URG	ENDO	OOR	BLOSS	ORW	Σ ORT_ENDO	ENDOSHARE	ENDO_ENDOSHARE	POST95

Appendix B

B.1 Estimation Results – OR Times

 Table 6: OLS Estimation Results Model 1

$\hat{\beta}_i$	Model 1
(Intercept)	3.395e+01 ***
$\Sigma \text{ ORT}_\text{ENDO}$	-2.372e-04 *
ASA_2	4.477e+00 ***
ASA_3	5.744e+00 ***
ASA_4	6.682e+00 *
ASA_5	2.453e + 01.
BLOSS	6.519e-02 ***
OOR	2.074e+01 ***
ORW	6.184e-01 ***
AGE	1.350e-01 ***
SUR_2	-1.481e+01.
SUR_3	1.347e+01 *
SUR_4	-1.132e+01 *
SUR_5	-2.774e+01 ***
SUR_6	-1.709e+01 **
SUR_7	1.621e+01 **
SUR_8	-7.779e + 00
SUR_9	7.989e + 00
SUR_{10}	-1.734e+01 **
SUR_{11}	6.547e + 00
Y1995	-2.873e + 00
Y1996	-1.389e + 00
Y1997	1.634e + 00
Y1998	4.895e + 00
Significance level	ls: *** 0.001 ** 0.01 * 0.05 . 0.1

\hat{eta}_i	ABD	\mathbf{EXT}	HEAD	NECK	PRO	THO	URO
(Intercept)	3.611e+01 **	3.471e+01 ***	-7.318e+00	1.498e+02 ***	12.4322052	2.825e+01	3.752e+01 ***
Σ ORT_ENDO	8.506e-05	-3.453e-04 *	2.624e-04	1.967e-06	-0.0005954 **	-2.622e-04	-3.232e-04 *
ASA_2	$3.705e{+}00$	$5.389e{+}00 **$	3.348e-01	-6.994e-01	2.3637388	1.077e+01	7.229e-01
ASA_3	7.533e+00.	4.460e+00.	-1.092e+01	$2.648e{+}00$	-2.3498966	1.318e + 01	4.204e+00.
ASA_4	7.028e+00	$9.106e{+}00 *$	-1.595e+01	-2.380e+01	-3.1184307	-7.240e+00	-1.034e+00
ASA_5	$9.448e{+}01$ *	$6.462\mathrm{e}{+00}$					
BLOSS	5.211e-02 ***	6.456e-02 ***	1.660e-01	1.606e-01 ***	0.0742338	8.947e-02 .	1.184e-01 ***
OOR	1.560e+01 ***	$2.128e{+}01 ***$	$4.733\mathrm{e}{+00}$	1.237e+01 ***	6.5625944 *	1.437e+01	$1.843e{+}01 ***$
ORW	7.204e-01 ***	4.114e-01 ***	$1.092\mathrm{e}{+00}$	5.778e-02	0.1886046	-3.921e-01	9.367e-01 ***
AGE	4.336e-01 ***	3.093e-02	2.976e-01 **	-5.329e-02	0.1973547 **	8.857e-02	1.386e-01 **
SUR_2	-3.074e+01	-5.000e+00		-1.371e+02 ***		-1.214e+01	
SUR_3	$8.726e{+}00$	1.013e+01	1.605e+01	-1.007e+02 ***	5.0130229	$3.152e{+}01$	-1.156e+00
SUR_4	-2.343e+01 *	-5.028e+00	3.756e+00	-1.135e+02 ***	0.1631922	1.569e+00	-1.924e+01 **
SUR_5			7.799e+00	-1.488e+02 ***			
SUR_6	-2.016e+01 .	-2.115e+01			6.3872256	-7.758e+00	-2.705e+01 ***
SUR_7	$7.260\mathrm{e}{+}00$	$1.805e{+}01 **$	2.902e+01 ***	-5.193e+01 ***	11.3604777	1.773e+01	$1.432e{+}01$
SUR_8	-2.916e+01 .	6.392e-01			5.3449095		
SUR_9	7.637e+00	$6.594\mathrm{e}{+}00$	1.229e+01	-1.211e+02 ***	19.2289214	4.105e+01	$-2.933e{+}01 $ *
${ m SUR}_{10}$	-1.488e + 01	-3.429e+00		-1.156e+02 ***	2.8719118	-4.111e+00	-3.007e+01 ***
SUR_{11}	-6.481e+00	1.115e+01.	2.434e+01 **		18.2831400	1.950e+01	
Y1995	-9.948e+00 *	9.664e-01	-9.079e+00	$3.531\mathrm{e}{+00}$	-1.4339179	-1.065e+01	$1.062\mathrm{e}{+00}$
Y1996	-1.310e+01 .	9.087e-01	-7.481e+00	$1.538e{+}00$	9.9178106	-2.874e+00	$6.107\mathrm{e}{+00}$
Y1997	-1.620e+01	$5.532\mathrm{e}{+}00$	-1.548e+01	-1.037e+00	22.2539640 *	2.357e+01	$9.566e{+}00$
Y1998	-1.517e+01	1.231e+01	-2.467e+01	-5.801e-01	29.4890753 *	-6.897e+00	$1.150e{+}01$
Significance leve	els: *** 0.001 **	0.01 * 0.05	0.1				

Table 7: OLS Estimation Results Model 2 for all OR Areas

\hat{eta}_i	ABD	EXT	HEAD	NECK	PRO	THO	URO
(Intercept)	$3.660e{+}01$ **	3.391e+01 ***	-1.904e+00	$1.499e{+}02 ***$	$1.095e{+}01$	28.3511367	$3.606e{+}01$ ***
Σ ORT_ENDO	-5.045e-05	-1.255e-04 *	-1.482e-04	1.008e-05	-2.500e-04 ***	-0.0006657 *	-2.062e-04 ***
ASA_2	$3.623\mathrm{e}{+00}$	$5.353e{+}00$ **	-1.740e+00	3.063e-02	$2.996e{+}00$	10.8734742	7.390e-01
ASA_3	7.253e+00.	4.514e+00.	-1.237e+01 *	$3.147e{+}00$	-9.914e-01	11.3891277	4.157e+00.
ASA_4	7.447e+00	$9.743e{+}00$ *	-1.844e+01 .	-2.224e+01	-4.178e+00	-8.0302405	-8.840e-01
ASA_5	$9.786e{+}01 $ *	7.028e+00					
BLOSS	5.253e-02 ***	6.472e-02 ***	2.386e-01 *	1.621e-01 ***	9.820e-02	0.0867583.	1.184e-01 ***
OOR	1.544e+01 ***	2.153e+01 ***	4.478e+00	1.171e+01 ***	$6.057e{+}00 *$	14.2988738	1.841e+01 ***
ORW	6.767e-01 ***	4.127e-01 ***	8.667e-01	7.344e-02	2.814e-01	0.1131130	9.441e-01 ***
AGE	4.388e-01 ***	2.907e-02	2.890e-01 **	-5.514e-02	1.879e-01 **	0.1103770	1.372e-01 **
SUR_2	-3.296e+01	-6.137e+00		-1.383e+02 ***		-3.5355970	
SUR_3	7.049e+00	$8.993e{+}00$	1.497e+01	-1.017e+02 ***	$2.816e{+}00$	43.1999971	-1.286e-01
SUR_4	-2.657e+01 *	-6.741e+00	$3.284\mathrm{e}{+00}$	-1.131e+02 ***	-1.782e+00	4.3499699	-1.852e+01 *
SUR_5			4.671e+00	-1.481e+02 ***			
SUR_6	-2.335e+01 *	$-2.098e \pm 01$			$4.175e{+}00$	1.0558820	-2.674e+01 ***
SUR_7	3.422e+00	$1.594e{+}01 *$	2.548e+01 ***	-5.137e+01 ***	$6.278e{+}00$	14.5011935	1.467e+01
SUR_8	-3.336e+01 *	-1.129e+00			-3.279e+00		
SUR_9	4.987e+00	$4.873\mathrm{e}{+00}$	$1.013\mathrm{e}{+01}$	-1.203e+02 ***	$1.590\mathrm{e}{+01}$	43.4673782	$-2.939e{+}01$ *
${ m SUR}_{10}$	-1.814e + 01	-4.769e+00		-1.162e+02 ***	-1.680e-01	-2.6062288	-2.965e+01 ***
SUR_{11}	-1.026e+01	8.781e+00	2.167e+01 *		$1.370e{+}01$	12.0019726	
POST95	-4.763e+00	-3.520e+00	6.197e+00	-1.157e+00	$5.464\mathrm{e}{+00}$	18.7765003	$3.652e{+}00$
Significance leve	ls: *** 0.001 *·	* 0.01 * 0.05 .	0.1				

Table 8: OLS Estimation Results Model 3 for all OR Areas

B.2 Estimation Results – Complications

\hat{eta}_{i}	Model 4	Model 5	Model 6	Model 7
(Intercept)	-4.1150706 ***	-4.2608314 ***	-3.6388099 ***	-3.8340231 ***
ENDO	0.1190866	0.6749374 *	0.1149080	0.7545548 *
ENDOSHARE	-0.0100414	-0.0009450	-0.0377516 ***	-0.0254161 **
ENDO_ENDOSHARE		-0.0247404 *	_	-0.0283773 *
ASA_2	0.5509073 *	0.5560100 *	0.5237654 *	0.5300570 *
ASA_3	1.1820989 ***	1.1854559 ***	1.1531142 ***	1.1577794 ***
ASA_4	1.6467060 ***	1.6558681 ***	1.6013062 ***	1.6150598 ***
ASA_5	2.4928265 *	2.4884713 *	2.561112 *	2.5567199 *
BLOSS	0.0008273 ***	0.0008455 ***	0.0008350 ***	0.0008583 ***
OOR	0.0323537	0.0309656	0.0372886	0.0355775
ORT	0.0030395 **	0.0028991 **	0.0029438 **	0.0027797 **
ORW	0.0190314 ***	0.0195914 ***	0.0154162 **	0.0161960 **
URG	0.0874675	0.0666938	0.0653750	0.0411569
AGE	0.0191165 ***	0.0189230 ***	0.0193232 ***	0.0190723 ***
SUR_2	0.4559373	0.4885770	0.3456965	0.3842505
SUR_3	0.4797772	0.4095788	0.3657179	0.2911479
SUR_4	0.3043972	0.2848515	0.3741794	0.3466818
SUR_5	-0.5256627	-0.5358020	-0.4537625	-0.4707663
SUR_6	-0.0100535	-0.0268609	0.0552987	0.0286494
SUR ₇	0.4136804	0.4218087	0.5373731	0.5410152
SUR ₈	0.2824505	0.2802919	0.2253498	0.2204730
SUR_9	0.1830913	0.1420697	0.2322303	0.1805951
SUR_{10}	0.1275411	0.1130276	0.1815025	0.1805951
SUR ₁₁	0.2438623	0.2550523	0.3686549	0.3779592
1995	0.0520472	0.0499908		—
1996	-0.4524836 **	-0.4578902 ***		_
1997	-1.1629633 ***	-1.1456894 ***		_
1998	-1.3142333 ***	-1.2696578 ***		_
POST95			-0.5923932 ***	-0.5967646 ***

 Table 9: Logit Estimation Results

Significance levels: *** 0.001 ** 0.01 * 0.05

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