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An Empirical Examination with German Data

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Corinna Hentschker and Roman Mennicken[1]

The Relationship between Quality and Hospital Case Volume – An Empirical Examination with German Data

Abstract

This paper examines the effects of hospital case volume on quality of care on the example of intact abdominal aortic aneurysm (AAA) and hip fracture (HIP). We conduct the analysis on patient level with multiple logistic regression analysis. Quality is measured with a binary variable which indicates whether the patient has died in hospital. The results show that patients who are treated in hospitals with a higher case volume have on average a significantly lower probability of death.

JEL Classification: I12, I18

Keywords: Volume; hospital quality; mortality

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1 Introduction

Quality in German hospital care is a topic of growing awareness for both, the public as well as policy makers. It is the main task of each hospital to improve patient's health outcome. Although every hospital is confronted with the same task it can be assumed that hospitals differ in their provided medical quality. The question arises if there are systematic differences which lead to good or poor outcome quality. A frequently discussed determinant of hospital quality is volume. It is hypothesized that hospitals with a higher case volume in an indication obtain a better outcome quality, i.e. the manufacturing's learning curve is applied to service organizations (Luft et al., 1987). Accumulated case volume of a hospital leads to decreasing adverse event rates through improvement of skills, standardization, and better organization (Birkmeyer et al., 2003; Gandjour and Lauterbach, 2003). Later, if learning reaches its plateau, high-volume hospitals are able to perform a procedure more regularly and therefore maintain their high level of learning (Gandjour and Lauterbach, 2003). Furthermore, economies of scale may play an important role in this context. Larger hospitals might have a broader skill-mix in staffing and a better training environment, which could positively impact health outcomes. Additionally, hospitals with higher volumes can more easily afford better technical equipment. In the volume outcome literature, these concepts are often referred to the "practice-makes-perfect" hypothesis (Seider et al., 2004)[1].

The volume-outcome relationship has been controversially discussed in the literature for more than three decades. For the first time, Luft et al. (1979) examined this relationship and found an inverse relation between mortality and case volume in ten out of twelve conditions. Numerous further publications followed with in-hospital mortality as the most commonly used indicator for outcome quality (Hughes et al., 1988; Wen et al., 1996; Birkmeyer et al., 2002; Barker et al., 2011).[2] In most cases the analyzes focus on specific conditions ranging from surgical or orthopaedic interventions for patients with heart diseases (Thiemann et al., 1999), cancer (Patti et al., 1998), or hip and knee fractures (Taylor et al., 1997) to the treatment of patients with AIDS (Hogg et al., 1998).

In this paper we analyze the volume-outcome relationship in German hospitals. We focus on from a health policy point of view two important conditions, intact abdominal aortic aneurysm without rupture (AAA) and hip fracture (HIP). Hip fracture[3] is one of the most frequent hospitalization reasons among older age groups in Germany (Statistisches Bundesamt, 2011). Due to the high incidence more than 1,000 hospitals in Germany treat those patients. In contrast, AAA[4] occurs far less frequently, i.e. treatment is performed

[1] Another possibility is that due to a better quality more patients or referring physicians choose the hospital for treatment which is called the "selective-referral" hypothesis. We will talk about the underlying causality assumptions in the discussion.

[2] Additional quality indicators are complications rates, length of stay, or death within a defined time interval (Browne et al., 2009; Forte et al., 2010).

[3] Hip fractures are fractures in the area of the hip which are mostly caused by falls. Treatment includes either a conservative therapy, a joint preserving therapy or a total or half replacement of the hip joint (Beck and Rüter, 1998).

[4] Abdominal aortic aneurysms are dilatations of the abdominal aorta of over three centimeters. An operation is necessary if the dilatation exceeds five centimeters. In this case, treatment is provided

by fewer hospitals. However, the treatment of AAA is complex and every mistake in the treatment process can lead to clinical complications (Agency for Healthcare Research and Quality, 2007). To sum it up, the two indications differ in prevalence and therefore volume rates as well as the number of hospitals in which the conditions are treated.

However, they are comparable as for both the outcomes depend highly on the hospital quality as international evidence suggests: Most empirical studies which examine the volume-outcome relationship of intact abdominal aortic aneurysm (AAA) found that the case volume of a hospital has a significant effect on quality (e.g. Birkmeyer et al., 2002; Dimick and Upchurch, 2008; Holt et al., 2009; Wen et al., 1996). Recent publications distinguish between patients with an open and an endovascular aneurysm repair (EVAR) (Dimick and Upchurch, 2008; Holt et al., 2009; Landon et al., 2010; McPhee et al., 2011). So far, evidence for Germany is lacking with only one study from Eckstein et al. (2007). They used clinical data from the years 1999 to 2004 with 10,163 patients from 131 hospitals. The authors only examined the effect of open aneurysm repair and found an inverse relationship between mortality and case volume between patients treated in hospital with the lowest case volume and patients in hospital with the highest case volume.

Hip fracture is less frequently evaluated in volume-outcome studies. Studies which consider hip fracture usually find no significant relationship between volume and outcome (Browne et al., 2009; Hamilton and Hamilton, 1997; Hamilton and Ho, 1998; Sund, 2010). Only Hughes et al. (1988) and Forte et al. (2010) find a significant relationship for patients with a hip fracture, but the study of Hughes et al. (1988) is criticized because of its insufficient risk adjustment (Hamilton and Hamilton, 1997). Except for Wenning et al. (2000) no studies using German data could be identified. They examined the volume-outcome effect for patients with a femoral neck fracture. The authors used data from 1993 to 1998 with a total of 26,005 patients and found significant differences in mortality rates between patients treated in hospitals with the lowest case volume and patients treated in hospitals with the highest case volume. But like Eckstein et al. (2007) the cluster structure of the data was not considered and no further hospital characteristics were added to the regression analysis.

We are the first to present a large scale study for Germany using a full in-patient sample of all 1,717 German hospitals. Additionally, we provide new evidence for a volume-outcome relationship for patients with a hip fracture, for which international evidence is sparse. The remaining part of this paper is organized as follows: Section 2 describes the data and the estimation strategy. Results are shown in Section 3, and Section 4 concludes.

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either with an open operation or with an endovascular aneurysm repair (EVAR) to avoid a rupture of the abdominal aorta (Torsello et al., 2005).

2 Data and Methods

2.1 Data

The analysis is based on administrative data generated by the German system of diagnosis related groups (DRGs)[5] of about 18.6 million hospital cases of 1,717 German hospitals from the year 2007. The data is a full sample of all in-hospital patients in Germany except psychiatric cases. The data are normally used for billing purposes towards insurance companies. They include detailed information on patient characteristics like age, gender, length of stay with admission and discharge date and status, main diagnosis[6] and secondary diagnoses given with the respective German ICD-10 codes. Additionally, the data contain information on hospital level about ownership type (private not-for-profit, private for-profit and public), bed capacity, and teaching status.

We use in-hospital mortality as a quality indicator. For both conditions, mortality is one of the inpatient quality indicators approved by the Agency for Healthcare Research and Quality (AHRQ) (Agency for Healthcare Research and Quality, 2007) and can therefore be used to examine differences in quality between hospitals. Mortality is a common quality indicator (Birkmeyer et al., 2002; Keeler et al., 1992) as it is the most serious clinical outcome. Additionally, in contrast to other outcome variables mortality is regarded as robust against different coding behavior of hospitals (AOK-Bundesverband et al., 2007). The latter point applies to the quality of the data set. Every hospital records its own data. Because hospitals know that the data is used for a qualitative evaluation it is possible that adverse events, for example complications, are not coded (Romano et al., 2002). Thus, we would not only evaluate quality differences but also coding differences between hospitals.

For this study we concentrate on patients with intact abdominal aortic aneurysm (AAA) and hip fracture. For AAA we use diagnosis and procedure codes which were defined by the German Federal Joint Committee in their quality assurance agreement for this condition (Gemeinsamer Bundesausschuss, 2010). This includes patients with an intact AAA who get an open or endovascular aneurysm repair (EVAR). Thus, patients with ruptured AAA were not subject of this analysis. We identified diagnoses for hip fracture patients by using the definition of the Federal Office for Quality Assurance (Bundesgeschäftsstelle Qualiätssicherung, 2008) and Browne et al. (2009). We include patients with a femoral neck or a pertrochanteric fracture who undergo either an open or closed reposition or get an implantation of an endoprothesis.

The identification strategy was as follows: First, we identified all potentially eligible patients for each condition by including all patients with a valid ICD-10 code as main or secondary diagnosis and a matching procedure code. Patients with an eligible ICD-10 but a missing procedure code are not included. Second, we exclude patients in each condition, if the respective condition was coded as a secondary diagnosis. These patients differ signifi-

[5] The data was used as part of the further development of the DRG-system.

[6] The German DRG system defines the main diagnosis as "the diagnosis, which is identified as primarily responsible for causing the hospital stay of the patient" (Deutsche Krankenhausgesellschaft et al., 2006).

cantly from patients with the condition as main diagnosis. They have, for example, a higher mortality rate and a longer length of stay. Hence, it has to be assumed that the outcome of these patients is primarily determined by their main diagnosis. For this reason, they are excluded from the sample. However, case volume was calculated by summing up all eligible patients including those with a secondary diagnosis and a ruptured AAA as the performance of these procedures also contributes to the learning effect of the hospitals (Landon et al., 2010). The exact identification algorithm for both conditions is given in the Appendix in Figure A1 and Figure A2. Accordingly, our temporary eligible sample consists of 8,405 AAA patients from 485 hospitals and of 99,705 hip fracture patients from 1,212 hospitals.

In general, it is recommended that for analyzes with mortality rates hospitals with less than one or rather less than five expected deaths should be excluded (Ash et al., 2003). In the present study especially hospitals with a low case volume are of importance because for these hospitals it is expected that they have the lowest quality. Therefore, it is not conducive to exclude them. Hence, we classify the case volume of hospitals in quintiles[7]. As a result, we can distinguish between patients who are treated in hospitals with a very low, low, medium, high, and very high case volume.

Except for volume the treatment effect is furthermore influenced by risk factors of the treated patients. For this reason, we control for age, gender, and admission status. A detailed definition of all variables is given in the Appendix in Table A1. Furthermore, we include an indicator variable for the type of hip fracture (only for hip fracture patients) and for the type of operative procedure (only for AAA patients). To account for number and severity of secondary diagnoses we use Charlson Comorbidity Index (Charlson et al., 1987). This is a standard approach for risk adjustment in the literature. For this purpose we use diagnosis codes of Quan et al. (2005) who mapped the original codes from ICD-9 system into the ICD-10 system. Another possibility for comorbidity risk adjustment is the method of Elixhauser et al. (1998). Both models lead to similar results. Therefore, only the estimates with Charlson Comorbidity Index are presented in this paper.[8]

Other studies have shown that next to volume further hospital characteristics, e.g. ownership (Milcent, 2005) or teaching status (Ayanian and Weissman, 2002; Keeler et al., 1992), could also responsible for a different quality of care. Hence, we include variables for teaching status, university hospital, ownership characteristics, hospital bed size, and location. As it is not possible to determine all hospital characteristics for all hospitals in the sample we lose some observations. The final sample for AAA consists of 8,301 patients treated in 478 hospitals and for hip fracture of 96,649 patients treated in 1,192 hospitals.

Table 1 and Table 2 show descriptive statistics of variables used in the analysis for AAA and hip fracture, respectively. The overall unadjusted in-hospital mortality rate is 3.5 % for AAA repair and 5.7 % for hip fracture treatment which are high mortality rates compared to an average hospital stay. The yearly case volume for the treatment of AAA ranges from 1 to

[7]This is a classification which is often used in the volume outcome literature. Nevertheless, this is an arbitrary division. Therefore, we also specified the case volume as a continuous variable and in tertiles. The case volume effect is robust for all different classifications.

[8]Regression results with Elixhauser comorbidities can be found in the Appendix in Table A2.

239 and for hip fracture from 1 to 434. Due to the classification of case volume in quintiles, we end up with an unequal distribution of the number of hospitals: In the quintile with the lowest case volume 62.8 % of the hospitals treat 21.5 % of the patients with AAA. In contrast, 19.5 % of the patients with AAA are treated in only 3.3 % of the hospitals with the highest case volume. This is similar for the distribution of hospitals with hip fracture treatment.

Table 1: Descriptive statistics of AAA

Variable		Case volume quintile (n = 8,301)				
	Total	1	2	3	4	5
(Range of cases)		(1-19)	(20-31)	(32-48)	(49-82)	(85-239)
Patients (n)	8,301	1,786	1,547	1,724	1,629	1,615
Deaths (%)	3.5	5.4	3.8	3.1	2.6	2.4
Hospitals (n)	478	300	75	57	30	16
Hospitals (%)	100.0	62.8	15.7	11.9	6.3	3.3
EVAR (%)	38.9	31.1	36.3	37.4	38.8	51.8
Male (%)	89.2	88.6	88.2	89.2	90.1	89.8
Mean age (years)	70.9	71.0	71.2	70.6	70.5	71.0
Admission reason (%)						
Scheduled admission	82.8	82.3	83.8	84.3	87.5	76.3
Emergency	13.2	15.4	13.3	13.0	8.9	15.3
Transfer	4.0	2.4	3.0	2.7	3.6	8.4
Charlson index (%)						
0	20.7	22.0	22.2	17.9	17.1	24.5
1-2	50.6	49.2	49.1	51.4	53.0	50.2
3-4	21.5	21.4	21.7	22.0	22.0	20.1
≥ 5	7.2	7.4	7.0	8.6	7.8	5.3
Ownership (%)						
Public	50.4	39.5	38.8	64.2	49.5	59.6
Private non-profit	32.3	44.4	48.7	25.9	25.3	17.3
Private for-profit	17.3	16.1	12.5	9.9	25.2	23.1
Teaching hospital (%)	75.0	64.7	73.1	80.7	78.1	78.9
University hospital (%)	1.4	0.1	0.0	2.0	0.0	5.2
Beds (%)						
< 200 Beds	4.6	9.2	7.6	0.0	6.3	0.0
201 to 1000 Beds	69.6	88.2	78.6	74.2	61.0	44.4
> 1000 Beds	25.8	2.6	13.8	25.8	32.8	55.6
Urban (%)	86.6	67.5	85.3	93.6	88.0	100.0

5,070 patients with AAA (61 %) underwent an open aneurysm repair and 3,231 patients (39 %) underwent EVAR. Though, the proportion of EVAR is in hospitals with a very high case volume with 52 % the highest. On average patients with AAA are 71 years old, are male and have a Charlson Comorbidity Index of 1.8. Patients with hip fracture are on average 80 years old, are female and have a Charlson Comorbidity Index of 1.4. In general, patients treated in hospitals with a higher case volume are more often treated in larger and urban hospitals.

2.2 Methods

We use multiple logistic regression analysis with y_{ih} indicating whether the patient i has died in hospital h ($y_{ih} = 1$) or not ($y_{ih} = 0$). We estimate the following equation via maximum

Table 2: Descriptive statistics of HIP

Variable	Total	Case volume quintile (n = 96,649)				
		1	2	3	4	5
(Range of cases)		(1-70)	(71-99)	(100-131)	(132-175)	(176-434)
Patients (n)	96,649	19,420	19,378	19,364	19,238	19,249
Deaths (%)	5.7	6.0	5.8	6.0	5.3	5.3
Hospitals (n)	1,192	534	245	183	136	94
Hospitals (%)	100.0	44.8	20.6	15.4	11.4	7.9
Femoral neck fracture (%)	53.6	56.4	54.1	52.6	52.8	52.3
Male (%)	25.1	24.5	25.0	25.4	25.8	25.1
Mean age (years)	79.6	79.7	79.5	79.5	79.5	79.7
Admission reason (%)						
Scheduled admission	21.4	27.5	23.6	18.3	19.7	17.8
Emergency	76.4	70.6	74.5	78.8	78.6	79.6
Transfer	2.2	1.9	1.9	2.9	1.7	2.6
Charlson index (%)						
0	35.8	35.6	35.3	35.9	36.5	35.5
1-2	43.3	43.4	44.0	43.6	43.3	42.2
3-4	15.3	15.4	14.8	14.9	15.0	16.2
≥ 5	5.7	5.7	6.0	5.6	5.1	6.1
Ownership (%)						
Public	48.0	36.2	40.4	44.4	53.3	65.9
Private non-profit	38.6	48.9	48.9	42.2	32.3	20.3
Private for-profit	13.4	14.8	10.7	13.3	14.4	13.8
Teaching hospital (%)	56.1	18.1	38.9	52.7	81.5	89.9
University hospital (%)	1.1	0.7	0.9	0.5	0.0	3.2
Beds (%)						
$<$ 200 Beds	20.0	63.6	23.8	7.9	0.7	3.9
201 to 1000 Beds	71.7	35.6	74.5	86.9	90.5	71.2
$>$ 1000 Beds	8.3	0.9	1.7	5.3	8.8	24.9
Urban (%)	75.1	60.6	70.0	74.7	80.4	90.0

likelihood estimation:

$$y^*_{ih} = \alpha_0 + \boldsymbol{vol'_h \beta_1} + \boldsymbol{x'_{ih} \beta_2} + \boldsymbol{k'_h \beta_3} + \varepsilon_{ih} \qquad (1)$$
$$y_{ih} = 1 \text{ if } y^*_{ih} \geq 0,$$

where y^*_{ih} is an unobserved latent variable which determines whether the patient died in hospital, vol is a categorical variable for the case volume, x are the patient characteristics, k are the hospital characteristics, and ε is a standard logistically distributed error term.

We use cluster-robust standard errors to account for the dependency of patients in the same hospital. Another possibility to account for the correlation of the error terms of patients in the same hospital is to add a random intercept to the model. Both approaches lead similar results. Therefore, we only present results with cluster-robust standard errors. However, it is important to account for the hierarchical structure of the data. Otherwise it leads to an underestimation of the variance or standard errors as the dependency of patients in the same hospitals is ignored. An issue often neglected as in e.g. Browne et al. (2009); McPhee et al. (2011); Wen et al. (1996) or Wenning et al. (2000).

3 Results

Estimation results for in-hospital mortality for AAA and hip fractures patients are shown in Table 3. For both indications a significant effect of case volume on quality is observable. We present results as odds ratios. Compared to patients with AAA treated in very low volume hospitals with less than 19 operations per year all other patients have a lower odds ratio for mortality. Though, those coefficients are significant only from the third volume quintile. For patients with hip fractures significant differences to patients treated in hospitals with the lowest case volume exists for patients treated in hospitals with more than 134 cases (as from the fourth case volume quintile).

Figure 1 shows the estimated average in-hospital mortality probability in each case volume quintile for both conditions with all other variables at their means. We can see a steady decrease of in-hospital mortality with an increasing case volume, except for the third case volume quintile for hip fracture patients. Patients with AAA who are treated in hospitals with less than 19 cases per year have an average probability of death of 3.3 % compared to an average mortality of 1.7 % for patients who are treated in hospitals with more than 85 cases. If all patients with AAA treated in hospitals with less than 19 cases per year (n = 1,786) would be treated in an average hospital of the fifth quintile 28 deaths could be presumably avoided.

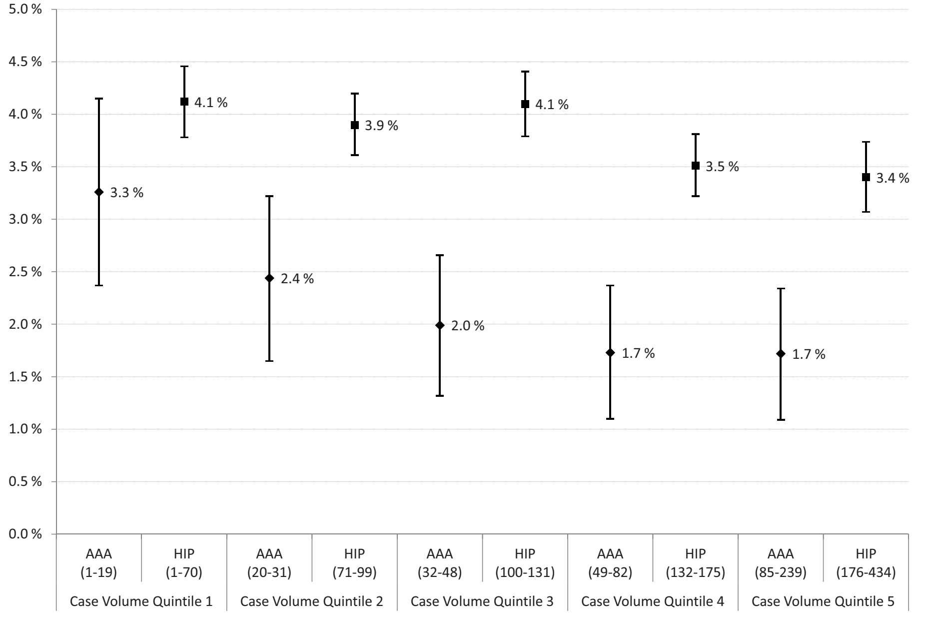
For patients with hip fracture the case volume effect is lower. However, compared to patients treated in hospitals with less than 70 cases per year the average probability of death for patients treated in hospitals with more than 176 cases is 0.7 percentage points less. Because of the higher incidence of hip fractures, in total 140 deaths per year could be

Table 3: In-hospital mortality estimates (logit)

	AAA		HIP	
	Odds Ratio	CI	Odds Ratio	CI
Case volume quintile2	0.7418	[0.4910,1.1206]	0.9441	[0.8498,1.0488]
Case volume quintile3	0.6026**	[0.3921,0.9261]	0.9935	[0.8856,1.1146]
Case volume quintile4	0.5243***	[0.3348,0.8210]	0.8465**	[0.7451,0.9618]
Case volume quintile5	0.5198***	[0.3207,0.8424]	0.8195***	[0.7110,0.9445]
Patient characteristics				
Age	1.0712***	[1.0512,1.0916]	1.0686***	[1.0645,1.0726]
Male	0.8107	[0.5728,1.1475]	1.7875***	[1.6747,1.9079]
Emergency	1.5259***	[1.1263,2.0672]	0.9508	[0.8836,1.0230]
Transfer	1.1894	[0.6204,2.2803]	1.3960***	[1.1638,1.6745]
EVAR	0.3823***	[0.2779,0.5258]		
Femoral neck fracture			1.0641**	[1.0065,1.1249]
Charlson index1	1.6881**	[1.0605,2.6872]	2.3383***	[2.1386,2.5566]
Charlson index2	4.3436***	[2.7631,6.8281]	4.3575***	[3.9480,4.8095]
Charlson index3	5.9823***	[3.5645,10.0400]	8.4268***	[7.5370,9.4218]
Hospital characteristics				
Private non-profit	1.2349	[0.8796,1.7339]	1.0415	[0.9669,1.1219]
Private for-profit	0.9851	[0.6681,1.4524]	1.0197	[0.9159,1.1352]
University hospital	0.4121*	[0.1451,1.1700]	0.6740	[0.3940,1.1530]
Teaching hospital	0.9876	[0.7127,1.3686]	1.0411	[0.9586,1.1308]
Beds2	1.1633	[0.6399,2.1149]	1.0522	[0.9466,1.1697]
Beds3	1.6810	[0.8696,3.2494]	1.0906	[0.9121,1.3040]
Urban	0.6444**	[0.4462,0.9306]	0.9625	[0.8938,1.0365]
Observations	8,301		96,708	
Number of hospitals	478		1,192	

Notes: Odds Ratios with 95% confidence intervals in brackets based on cluster-robust standard errors; * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Figure 1: Probability of death with 95 %-CI per case volume quintile for AAA and hip fracture patients



presumably avoided if all patients treated in hospitals with less than 70 cases (n = 19,420) were treated in an average hospital of the fifth quintile.

Patient characteristics are consistently significant for both AAA and hip fracture models. It is found that increasing age, increasing number and severity of comorbidities are associated with a significant increase in the odds of mortality for both indications. Compared to patients with open aneurysm repair patients with an EVAR have a significant lower odds of mortality. The odds of mortality are also significant higher for men compared to women in the hip fracture treatment. In contrast, hospital characteristics have no significant effect on mortality.

4 Discussion

4.1 Limitations

The relationship between case volume and quality can be explained with two hypotheses with opposite causality directions. The "practice-makes-perfect" hypothesis states that an increasing case volume in a specific indication improves the outcome quality. The opposite causal direction is called the "selective-referral" hypothesis, which states that because of the high quality of a hospital the case volume increases. If the latter is true, than our estimate of the volume effect would be biased. However, instrumenting volume with the number of potential patients and on the number of further hospitals in the regional area Gaynor et al. (2005) did not lead to different results, at least for CABG patients. Additionally, "selective-referral" assumes that quality information is readily available, so that patients can make a choice based on quality information. Even though there is some evidence, that patients choose hospitals based on quality (Varkevisser et al., 2012), readily accessible information about quality in German hospitals only became available during summer 2007. Hence, it is unlikely that the publication of so called "quality reports" could heavily influence the results with our data from 2007.

Furthermore, hospital choice models sensibly assume that there is a correlation between patients' severity of disease and hospital choice (Gowrisankaran and Town, 1999). As we have the zip codes of all our patients and the exact address of the hospital we computed travel times for all our patients (shown in the Appendix). We cannot detect any differences in travel time for disease severity measured by Charlson Comorbidity Index. Nevertheless, as we cannot fully rule out that unobservable characteristics of the patients correlate with their hospital choice, further research is necessary.

4.2 Conclusion

In this study we have estimated the effect of case volume on outcome based on a full sample of administrative data from the year 2007. We have shown a significantly inverse relationship between volume and mortality for the treatment of patients with AAA and hip fracture.

We are the first who provide estimates for the number of lives that could potentially be saved. Even though we are confident that the causal direction goes from volume to outcome, it is important to stress that we only found evidence for a correlation so far. As pointed out before, it is essential to assess the direction of causality also empirically by using an instrumental approach. If volume triggers quality, a concentration of certain procedures would lead to an increase in the overall quality of medical care. As a result, only hospitals with a certain case volume would be allowed to treat patients with e.g. AAA or hip fracture. Accordingly, hospitals with a very low volume would be forced to exit the market by minimum-volume regulations.

In this case, further research is necessary to evaluate whether sufficient medical services are locally provided in the treatment for AAA or hip fracture patients. For example, if all hospitals in the first quintile of AAA had to exit the market, 300 hospitals, i.e. nearly two third of all hospitals, would not provide any further services in treating AAA. Depending on the area a closure could compromise provision of services. To ensure an adequate access to health services travel time for patients must not exceed a certain amount of time. If travel time in regions exceeds a certain threshold, it could be beneficiary to allow so called "sole providers" (Gale and Coburn, 2003; Ricketts and Heaphy, 2000) to stay in the market. Furthermore, if minimum-volume regulations are introduced, capacity thresholds of high-volume and high quality hospitals have to be accounted for when treating additional patients from closed low volume hospitals.

A Appendix

Table A1: Variable definitions

Variable	Definition
Patient characteristics	
Mortality	1, if patient died in hospital, 0 otherwise
EVAR (AAA)	1, if EVAR, 0 otherwise
Femoral neck fracture (HIP)	1, if femoral neck fracture, 0 otherwise
Age	Age in years
Male	1, if male, 0 otherwise
Admission*	1, if admission by the doctor, 0 otherwise
Emergency	1, if admission as emergency, 0 otherwise
Transfer	1, if admission from another hospital, 0 otherwise
Charlson index 0*	1, if Charlson Comorbidity Index = 0, 0 otherwise
Charlson index 1	1, if Charlson Comorbidity Index = 1 or = 2, 0 otherwise
Charlson index 2	1, if Charlson Comorbidity Index = 3 or = 4, 0 otherwise
Charlson index 3	1, if Charlson Comorbidity Index $\geq$ 5, 0 otherwise
Hospital characteristics	
Case volume quintiles AAA	
Case volume quintile 1*	Volume > 1 and $\leq$ 19
Case volume quintile 2	Volume > 20 and $\leq$ 31
Case volume quintile 3	Volume > 32 and $\leq$ 48
Case volume quintile 4	Volume > 49 and $\leq$ 82
Case volume quintile 5	Volume > 85 and $\leq$ 239
Case volume quintiles HIP	
Case volume quintile 1*	Volume > 1 and $\leq$ 70
Case volume quintile 2	Volume > 71 and $\leq$ 99
Case volume quintile 3	Volume > 100 and $\leq$ 131
Case volume quintile 4	Volume > 132 and $\leq$ 175
Case volume quintile 5	Volume > 176 and $\leq$ 434
Teaching hospital	1, if teaching hospital, 0 otherwise
University hospital	1, if university hospital, 0 otherwise
Public*	1, if publicly owned hospital, 0 otherwise
Private non-profit	1, if private non-profit hospital, 0 otherwise
Private for-profit	1, if private for-profit hospital, 0 otherwise
Beds1*	1, if number of beds $\leq$ 200, 0 otherwise
Beds2	1, if number of beds > 200 and $\leq$ 1000, 0 otherwise
Beds3	1, if number of beds > 1000, 0 otherwise
Urban	1, if regional structure is urban, 0 otherwise

Note: * – omitted category

Figure A1: Inclusion and exclusion criteria for patients with AAA

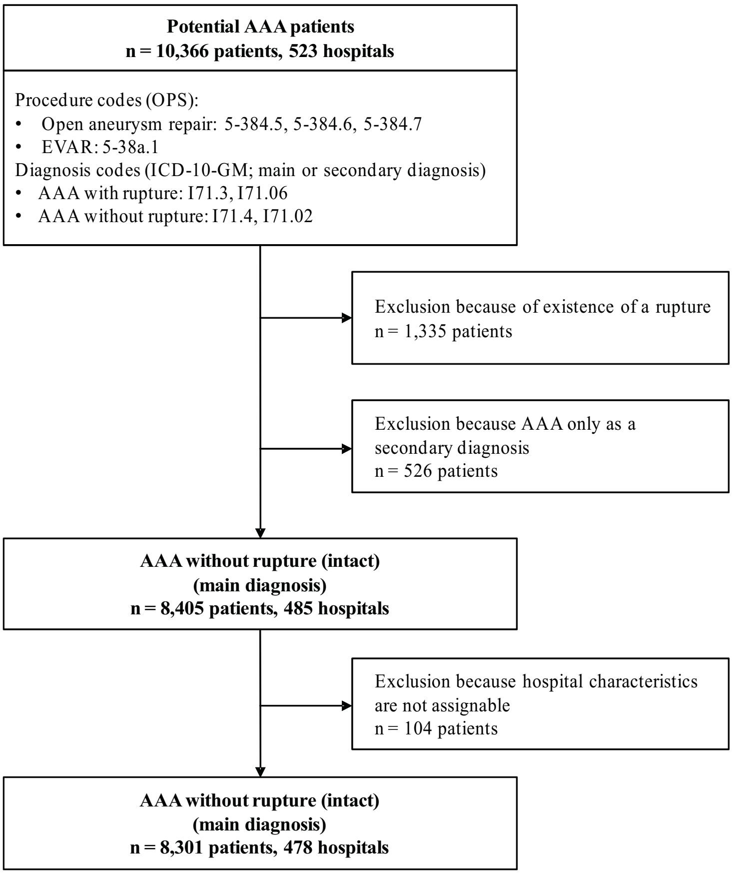
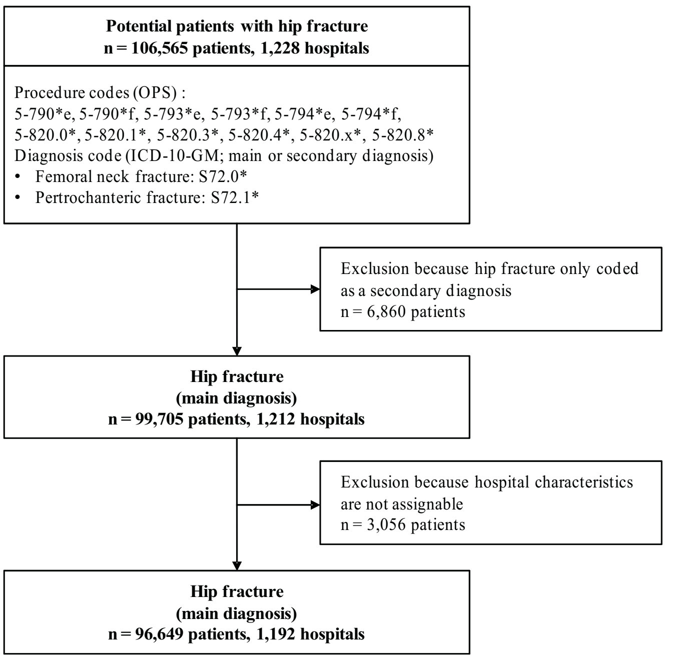


Figure A2: Inclusion and exclusion criteria for patients with hip fracture



Note: * - stands for all possible subcategories

Table A2: In-hospital mortality estimates with Elixhauser comorbidities (logit)

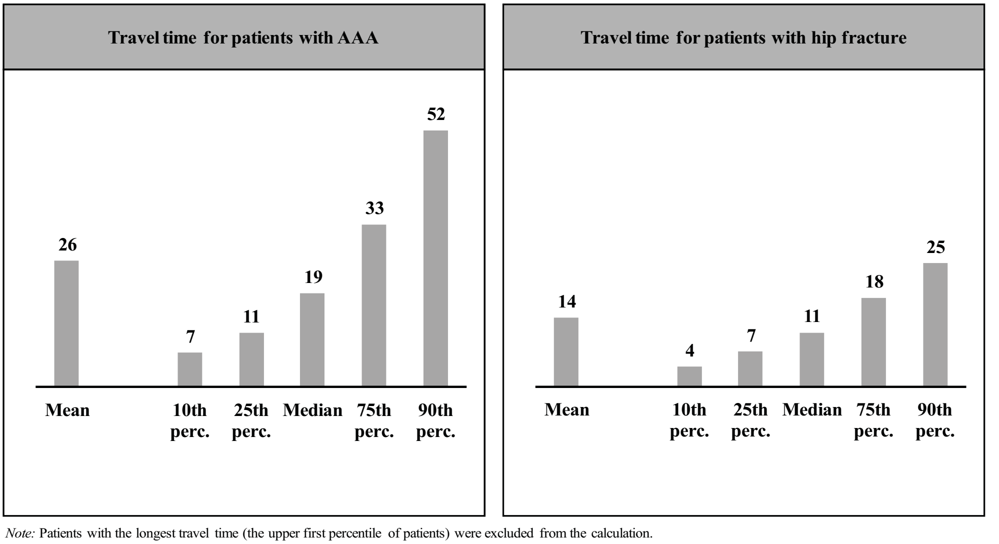
	AAA		HIP	
	Odds Ratio	CI	Odds Ratio	CI
Case volume quintile2	0.7394	[0.4817,1.1350]	0.9622	[0.8595,1.0772]
Case volume quintile3	0.6399*	[0.4009,1.0214]	1.0153	[0.8971,1.1491]
Case volume quintile4	0.5416**	[0.3331,0.8806]	0.8326***	[0.7253,0.9558]
Case volume quintile5	0.5223**	[0.2957,0.9225]	0.8034***	[0.6851,0.9422]
Patient characteristics				
Age	1.0652***	[1.0441,1.0868]	1.0695***	[1.0653,1.0738]
Male	0.7620	[0.5287,1.0981]	1.7316***	[1.6115,1.8606]
Emergency	1.2154	[0.8645,1.7088]	0.9527	[0.8822,1.0288]
Transfer	1.0328	[0.5317,2.0063]	1.3559***	[1.1089,1.6578]
EVAR	0.4831***	[0.3440,0.6783]		
Femoral neck fracture			1.0311	[0.9729,1.0928]
Congestive Heart Failure	1.6130***	[1.1701,2.2234]	2.6789***	[2.4928,2.8788]
Cardiac arrhythmias	1.7360***	[1.2928,2.3310]	1.5732***	[1.4684,1.6855]
Valvular disease	1.0126	[0.6598,1.5538]	0.8602**	[0.7513,0.9848]
Pulmonary circulation disorders	2.2826**	[1.0801,4.8236]	7.9985***	[6.9100,9.2584]
Peripheral Vascular Disease	1.4032**	[1.0285,1.9143]	1.2687***	[1.1205,1.4365]
Hypertension, uncomplicated	0.4629***	[0.3499,0.6124]	0.6646***	[0.6224,0.7098]
Hypertension, complicated	0.5114***	[0.3255,0.8033]	0.5423***	[0.4793,0.6136]
Paralysis	2.7828***	[1.4433,5.3654]	1.5058***	[1.3151,1.7241]
Other neurological disorders	2.2676***	[1.2340,4.1670]	1.2051***	[1.0917,1.3303]
Chronic pulmonary disease	1.1228	[0.8345,1.5107]	1.1411***	[1.0354,1.2576]
Diabetes, uncomplicated	1.0211	[0.6606,1.5782]	1.1002**	[1.0138,1.1940]
Diabetes, complicated	0.9614	[0.5122,1.8045]	1.3611***	[1.2012,1.5423]
Hypothyroidism	0.9081	[0.4618,1.7857]	0.6477***	[0.5465,0.7676]
Renal failure	1.7869***	[1.3197,2.4193]	1.5183***	[1.4033,1.6427]
Liver disease	3.1031***	[1.8158,5.3029]	3.9091***	[3.2561,4.6930]
Peptic ulcer disease excluding bleeding	0.3566	[0.0592,2.1469]	0.5849*	[0.3112,1.0994]
Lymphoma	1.7186	[0.3213,9.1936]	1.5154*	[0.9805,2.3419]
Metastatic cancer	1.3278	[0.1461,12.0693]	4.3844***	[3.5085,5.4790]
Solid tumor without metastasis	1.2682	[0.6482,2.4814]	2.0543***	[1.7361,2.4308]
Rheumatoid arthritis/collagen vasc. diseases	0.2550	[0.0338,1.9261]	1.1332	[0.8860,1.4494]
Coagulopathy	5.0386***	[3.7665,6.7403]	2.2217***	[1.9566,2.5227]
Obesity	0.7945	[0.5654,1.1166]	0.7401***	[0.6285,0.8715]
Weight loss	0.9320	[0.2277,3.8152]	1.8975***	[1.6459,2.1875]
Fluid and electrolyte disorder	1.4152**	[1.0516,1.9045]	1.3276***	[1.2334,1.4290]
Blood loss anemia	1.9932*	[0.9069,4.3807]	0.8021*	[0.6276,1.0252]
Deficiency anemia	0.2086	[0.0192,2.2620]	0.6848***	[0.5363,0.8745]
Alcohol abuse	1.9845*	[0.9860,3.9941]	1.2482**	[1.0280,1.5156]
Drug abuse	0.8263	[0.3735,1.8280]	0.7997*	[0.6267,1.0205]
Psychoses	4.0587**	[1.0640,15.4827]	0.9115	[0.6439,1.2901]
Depression	0.3314	[0.0639,1.7177]	0.6150***	[0.5260,0.7191]

Continued on the next page.

	AAA		HIP	
	Odds Ratio	CI	Odds Ratio	CI
Hospital characteristics				
Private non-profit	1.3840*	[0.9509,2.0142]	1.0609	[0.9764,1.1527]
Private for-profit	1.0850	[0.7184,1.6387]	1.0608	[0.9421,1.1944]
University hospital	0.4325*	[0.1677,1.1154]	0.5506*	[0.2733,1.1093]
Teaching hospital	0.8774	[0.6186,1.2443]	1.0289	[0.9385,1.1280]
Beds2	1.2405	[0.6658,2.3113]	1.0887	[0.9713,1.2204]
Beds3	1.5664	[0.7716,3.1801]	1.0818	[0.8858,1.3212]
Urban	0.6923*	[0.4707,1.0182]	0.9357	[0.8631,1.0144]
Observations	8,300		96,630	
Number of hospitals	478		1,192	

Notes: Odds Ratios with 95% confidence intervals in brackets based on cluster-robust standard errors; * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Figure A3: Distribution of travel time for patients with AAA and HIP (in minutes)



Note: Patients with the longest travel time (the upper first percentile of patients) were excluded from the calculation.

Table A3: Mean travel time, standard deviations and distribution of travel time by selected characteristics

Characteristics	Obs.	Mean[1)]	s.d.[1)]	0-10 min	10-20 min	20-30 min	>30 min
			AAA				
All patients	8,257	25.5	21.4	22.1%	30.6%	18.7%	28.7%
Age							
≤ 70 years	3,896	25.8	21.3	21.0%	30.4%	19.3%	29.3%
> 70 years	4,361	25.3	21.5	23.1%	30.8%	18.1%	28.1%
Charlson Index							
Charlson Index 0	1,712	25.4	22.0	22.0%	32.4%	17.7%	27.9%
Charlson Index 1-2	4,175	25.7	21.3	21.5%	30.4%	18.9%	29.2%
Charlson Index 3-4	1,772	25.8	21.7	22.8%	29.6%	18.7%	29.0%
Charlson Index ≥ 5	598	24.2	19.3	24.4%	29.9%	19.4%	26.3%
Patient Clinical Complexity Level (PCCL)[2)]							
PCCL 0	1,659	25.8	21.2	21.3%	30.4%	18.6%	29.7%
PCCL 1-2	190	28.7	24.4	19.5%	30.0%	16.8%	33.7%
PCCL 3	1,679	26.4	22.5	21.0%	30.1%	17.9%	31.0%
PCCL 4	3,434	24.9	21.0	23.1%	30.7%	19.4%	26.8%
Region							
East Germany	937	29.9	24.3	22.0%	22.0%	18.1%	37.9%
West Germany	7,320	25.0	20.9	22.1%	31.7%	18.7%	27.5%
Structure							
Urban	7,146	24.8	20.8	22.4%	32.4%	18.3%	26.9%
Rural	1,111	30.0	24.4	20.3%	19.3%	20.8%	39.7%

Characteristics	Obs.	Mean[1)]	s.d.[1)]	0-10 min	10-20 min	20-30 min	>30 min
			HIP				
All patients	95,831	13.9	12.0	46.1%	35.2%	12.5%	6.2%
Age							
≤ 70 years	16,016	15.8	14.8	41.2%	35.2%	13.4%	10.3%
> 70 years	79,815	13.5	11.4	47.0%	35.3%	12.3%	5.4%
Charlson Index							
Charlson Index 0	34,171	14.4	13.3	45.1%	34.7%	12.7%	7.5%
Charlson Index 1-2	41,549	13.6	11.4	46.9%	35.4%	12.2%	5.5%
Charlson Index 3-4	14,647	13.6	11.0	46.4%	35.9%	12.5%	5.2%
Charlson Index ≥ 5	5,464	13.9	10.8	44.7%	36.0%	13.3%	6.0%
Patient Clinical Complexity Level (PCCL)[2)]							
PCCL 0	13,993	14.9	13.6	43.5%	34.4%	13.3%	8.8%
PCCL 1-2	10,152	14.1	12.4	45.5%	34.8%	12.9%	6.8%
PCCL 3	19,707	13.8	12.0	46.4%	35.1%	12.5%	6.1%
PCCL 4	38,948	13.7	11.5	46.6%	35.4%	12.4%	5.5%
Region							
East Germany	14,147	15.9	13.1	39.0%	34.9%	16.2%	9.9%
West Germany	81,684	13.6	11.8	47.3%	35.3%	11.8%	5.6%
Structure							
Urban	71,881	12.8	10.8	49.8%	36.0%	9.9%	4.3%
Rural	23,950	17.3	14.7	34.7%	32.9%	20.2%	12.1%

Notes: [1)]Patients with the longest travel time (the upper first percentile of patients) were excluded from the calculation of the mean and the standard deviation.
[2)]The PCCL is specific to the German DRG system and measures the different resource consumption of patients within the same DRG, accounting for possible multimorbidity. The PCCL is calculated during the billing process using secondary diagnoses, i.e., a higher PCCL leads c.p. to higher reimbursement for the hospital. The values of the PCCL range from zero (non-severe) to four (most severe).

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