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Justus Vogel, Johannes Hollenbach, Alexander Haering, Boris Augurzky, and Alexander Geissler[1]

Are Profitable Hospitals More Digitally Mature? – An Explorative Study Using Data from the German DigitalRadar Project

Abstract

Public investment in hospitals in Germany has been insufficient for decades, making it difficult to finance digitization. Due to dual financing, hospitals could alternatively use their own profits to pay for digitization efforts. This raises the question of whether there is a relationship between profitability and digitization, i.e., whether profitable hospitals are more digitally mature, and what other factors might influence digital maturity. To investigate this relationship, we use novel data on digital maturity of German hospitals and combine them with balance sheet data. Our multivariate regression results do not show a robust correlation between profitability and digital maturity. Rather, being part of a large chain seems to be more important for digitalization. We conclude that hospitals in chains are more digitally mature because they benefit from a standardization of IT infrastructure and internal policies. Individual hospitals may also benefit from centralizing parts of their IT strategy development.

JEL-Codes: I11; I18; M15

Keywords: Hospital profitability; hospital digitization; digital maturity

May 2023

1 Justus Vogel, University of St. Gallen, Switzerland; Johannes Hollenbach, RWI; Alexander Haering, RWI; Boris Augurzky, RWI; Alexander Geissler, University of St. Gallen, Switzerland. *- We thank all our colleagues of the Konsortium DigitalRadar Krankenhaus for the constructive project work, the German Federal Ministry of Health (BMG) as well as all hospitals participating in the evaluation project. Special thanks to Astrid Wering.* *– All correspondence to: Justus Vogel, Chair of Healthcare Management, School of Management, University of St. Gallen, St.-Jakob-Str. 21, 9000 St. Gallen, Switzerland, e-mail: justus.vogel@unisg.ch*

1 Introduction

Digitization of organizations and production processes has been on the rise for decades. However, the hospital sector has only recently begun to catch up to other industries [1]. Moreover, hospital digitization in Germany is slow compared to other countries [1–5]. Without digitization, however, potential improvements in information flow, process productivity and, most importantly, quality of care cannot be realized. Stephani et al. [3] argue that reasons for German hospitals' digitization deficit is due to overly strongly concerns about data protection, the poor user-friendliness of existing hospital information systems, insufficient broadband connection, and a lack of investment in digitization.

In fact, financing investment in digitization is rather challenging for German hospitals. Generally, there are two possibilities [6, 7]. Firstly, hospitals listed in a federal state's hospital capacity plan receive state funded flat rate grants and/or can apply for a state grant. Flat rate grants are meant to be used for short-term assets and minor constructions while state grants are commonly used for construction and/or renovation of buildings, and purchase of large-scale medical technology. Innovative soft- and hardware with – compared to construction projects – smaller investment needs are often neglected [7]. This could have several reasons: First, there might be no management capacity left to handle additional application processes apart from construction projects, the time and effort needed for applications is too large for the respective investment sums, applications for software might compete with one's own applications for more expensive projects (and could possibly impede their approval at the state health ministry) and lastly, (economical) benefits might be unclear.

Secondly, investments could be financed with own profits and cash flow. In the German DRG-based flat rate payment regime, investments are not included, however, since officially, investments should be financed by a hospital's federal state [8, 9], as discussed above. This so-

called “dual financing” is rather dysfunctional: In 2018, for instance, only about half of hospitals’ investment needs were financed with state funding [7]. At the same time, Augurzky et al. show that 34% and 28% of all investigated hospitals in 2019 and 2020, respectively, ran a deficit and that the average earnings margin was at 0.6% and 1.2% in 2019 and 2020, respectively [10].

Generally, higher digitization is associated with higher productivity, increased efficiency, and better quality of care. Existing studies on the relationship between hospital profitability and digital maturity focus on Australia, the United States, and the United Kingdom. European studies on this topic are scarce (e.g., [11–13]) and to the best of our knowledge, there is no research that specifically examines Germany, apart from a benchmarking study [3]. Moreover, datasets on digital maturity usually only include a (small) subset of a country’s hospital landscape. Lastly, understanding hospitals’ challenges regarding investments in digitization better is very pressing in Germany and beyond.

Given this state of the literature and the German context, we investigate the following explorative research questions:

1. Is a hospital’s digital maturity associated with its profitability?
2. What other hospital characteristics are associated with hospitals’ digital maturity?

Answering the first research question will shed light on whether profitable hospitals might use own resources to finance digitization. Investigating the second research question, we explore whether factors such as hospital size, ownership, or chain membership synergies play a role in hospital digitization.

In response to the challenges of hospital digitization in Germany described above, the government created the Hospital Future Act which came into effect in 2020. It provides an investment budget of € 4.3 billion for hospital digitization [14]. Eleven fundable topics were

identified ranging from patient portals, emergency care, (semi-) automated clinical decision support systems, and medication management to equipping patient rooms. Until the second quarter of 2021, hospitals could apply for investment funding for one or more fundable topics. Still, hospitals are required to partially finance digitization projects themselves. The policy measure sets the incentive that hospitals not applying for funding or rather failing to increase their level of digitization must accept a deduction of DRG flat rate payments. The Hospital Future Act's goal is to increase digitization as a means to improve and to ensure long-term stability of quality of care as well as to establish a new way of working for hospital staff.

Part of the Hospital Future Act is the evaluation of its investment program in the "DigitalRadar" (DR) project. For the evaluation, data on hospitals' status quo level of digital maturity was collected nationwide from October to December 2021 and hospitals' digital maturity was assessed with the newly developed DigitalRadar-Score ("DR-score"). To answer the above research questions, our explorative empirical strategy is twofold: First, we identify potentially influential hospital characteristics such as chain membership and chain size using descriptive statistics. Second, we conduct multivariate linear regressions with hospitals' DR-score as dependent and hospitals' EBITDA margin as variable of interest.

We contribute to the literature in three ways: (1) We combine a nationwide dataset on digital maturity with hospital financial statement data allowing us to analyze a large hospital dataset, (2) we provide first evidence for Germany, and lastly (3) our results inform health policy makers, and hospital management in Germany and beyond.

2 Data and methods

Generally, each hospital in Germany is comprised of one or more sites and may be part of a hospital chain. Accordingly, there are three data levels: (1) hospital site, (2) hospital, and (3)

chain. We aim to generate evidence on hospital site level. Our data sources report data on all three levels (or geographical level), however (see Table 1). Thus, where needed, we matched more aggregated data levels with hospital sites.

Table 1: Overview of used data sources, variables, data years, data levels and data matching

Data category	Source(s)	Variable(s)	Data year	Data level	Matched to hospital sites via…
Digital maturity	DigitalRadar [2]	DR-score	2021	Hospital site	-
Profitability	Hospital Rating Report 2022 [10] Dafne database [15]	EBITDA margin	2020	Hospital site or hospital chain	If a hospital is part of a chain, the chain EBITDA margin was assigned to all sites of a chain
Hospital characteristics	German Hospital Directory [16]	Number of beds, ownership type	2021	Hospital site or hospital	If needed, hospital site addresses were used in addition to unique hospital identifiers
	Hospital Rating Report 2022 [10]	Chain membership	2020		
	INKAR database [17]	Federal state	2021		
County level controls	INKAR database [17]	Income tax revenue, population density	2021	County	Zip-code of hospital site was matched with zip-code's county ID

Digitization

We use the DR-score, a novel measure developed as part of the DR evaluation project [2]. It allows for the standardized assessment of digital maturity of German hospitals and ranges from 0 (not digitized) to 100 (fully digitized). Hospitals applying for funding were required to fill out a questionnaire, sent out between October and December 2021. In order to receive the funds, it was mandatory for all hospitals to complete the questionnaire. A total of 1,624 hospitals participated in the survey. Hospitals were asked questions covering a range of aspects of hospital digitization ("dimensions") connected to the fundable topics of the Hospital Future Act. Dimensions include structural elements, clinical, administrative, and data-related

processes as well as telehealth and patient participation. Questions are scored individually according to their type (e.g., single-choice, or multiple-choice).

To calculate the DR-score, first, points within each dimension are added. The dimensions contain different numbers of questions. Consequently, not all answers contribute equally to the total DR-score. Questions in dimensions that have many questions assigned to them have relatively less weight, while questions from smaller dimensions have a comparatively greater influence on the aggregate score. Moreover, since the dimensions have different importance, subtotals of dimensions are weighted before being aggregated to the final DR-score. The weights were set by an advisory board of experts and reflect the relative importance of each of the dimensions for hospital digitization.

In order to establish comparability between different hospital types, psychiatric hospitals and hospitals without emergency department were treated differently when calculating the DR-score. Firstly, DR-scores of psychiatric hospitals were adjusted by considering only the subset of questions relevant to the treatment of psychiatric patients. Secondly, when calculating the score, questions concerning emergency care where disregarded for hospitals without emergency department. Incidentally, if a question was irrelevant for a hospital, respondents had the option to mark questions as "not applicable". This mainly concerned questions related to equipment relevant only for a certain subset of hospitals as for instance network integration of robotic-assisted surgery systems.

For an even more detailed description of the survey, data cleaning methodology, and final dataset, see the publication by the evaluating body [2].

Profitability

As outlined above, profitable hospitals may use their cash flow to finance (large) one-time payments for software purchases and/or they may manage to cover operating expenses from

software licensing fees, software maintenance, and/or software-as-a-service payments. Therefore, a measure representing profitability should adequately reflect both cash flow and operating profitability. The EBITDA margin shows both characteristics:[1] (1) It represents profits from operations, i.e., revenue after deducting labor costs and material expenses, divided by total revenue and (2) as such, it is a good representation of a company's cash flow, especially in industries such as the hospital sector where accounts payable are relatively low and where depreciation and amortization are large components of total expenditures [10, 18]. The data used in our analysis are part of a panel of balance sheet items of German hospitals forming the basis of Augurzky et al. [10], sourced from the Dafne database [15] containing standardized information about German companies.

Hospital characteristics

With respect to hospital characteristics, we use several control variables such as the number of beds, type of ownership (private, public, or nonprofit), federal state, whether the hospital is part of a chain and – if applicable – the size of the chain. The data are either sourced from Augurzky et al. [10] in the case of the variable "chain membership", taken from the German Hospital Directory (*Krankenhausverzeichnis*) [16] or from the INKAR database [17]. If unique hospital identifiers did not suffice to match hospital characteristics data to single hospital sites, hospital site addresses were used additionally.

[1] In accordance with German hospital accounting guidelines, federal investments are implicitly included in hospitals' EBITDA. However, to obtain a comparable measure of profitability across federal states and the correct measure to address our research questions, investment funds are manually deducted from hospitals' EBITDA.

County level controls

Lastly, we include two county level variables taken from the INKAR database [17], namely income tax revenue terciles and population density terciles, to control for county specific effects. Variables are linked to hospital sites by connecting hospital zip codes to counties. If the area of a zip code overlaps with multiple counties, the county with the largest share of the zip code area is assigned to the hospital.

Dataset and sample

Data from the different sources was matched using unique hospital identifiers and/or hospital address data. Our final sample includes a cross-section of 756 German hospitals, i.e., about half of the hospitals surveyed for the DR evaluation project and roughly 45% of all German hospitals. Digital maturity was measured between October and December 2021, whereas the balance sheet data refers to 2020. We argue that effects from using profits for digitization are time-lagged, as it takes time to implement software, new processes, practices, and networks. Moreover, hospitals first need to generate digitization funding and/or create expenditure budgets by being profitable before they can spend money on digitization.

We use EBITDA margin on company level for all hospitals. For single hospitals, this means that we use EBITDA margin on hospital or hospital site level. For hospitals that are part of a chain, we use the EBITDA margin of their chain. Overall, chain EBITDA margins were assigned to 381 hospitals, i.e., to about 50% of the investigated sample.

Empirical Approach and Statistical Model

We follow a two-step explorative approach: Potentially influential variables were identified using descriptive statistics (see supplementary material). Second, we run multivariate linear regressions with hospitals' digital maturity as the dependent variable and hospitals' EBITDA margin as variable of interest, adding and/or substituting controls and interaction terms with

each new regression. We estimate the profitability-digitization relationship using Ordinary Least Squares (OLS) regression

$$y_i = \beta_0 + \beta_{\mathrm{e,i}} E_i + X_i' \beta_{\mathrm{x,i}} + C_i' \beta_{\mathrm{c,i}} + \varepsilon_i$$

where y is the DR-score of hospital site i. E_i is the EBITDA margin of hospital site i, i.e., either the hospital's own EBITDA margin in the case of single hospitals or chain-level EBITDA margin if the hospital belongs to a chain. X_i' is a vector of control variables of hospital characteristics such as chain membership, number of beds, ownership type, chain size terciles by number of beds and federal state-fixed effects. The exact composition of X_i' depends on the respective regression. C_i' represents the county level controls. ε_i are heteroskedasticity-robust standard errors.

Since we control for many potential confounders of the effect of EBITDA margin on digital maturity, we can alleviate some concerns regarding omitted variable bias. Regardless, our results cannot be interpreted as estimates of a causal effect, since it is likely that there are other (un-)observable factors we cannot control for as well as reverse causality or simultaneity present in the relationship. That is, higher profitability and a correspondingly higher cash flow may increase digital maturity via higher investments and/or expenditures, while a higher digital maturity may, in turn, also lead to higher profitability, e.g., via more efficient processes (cf. section 4).

3 Results

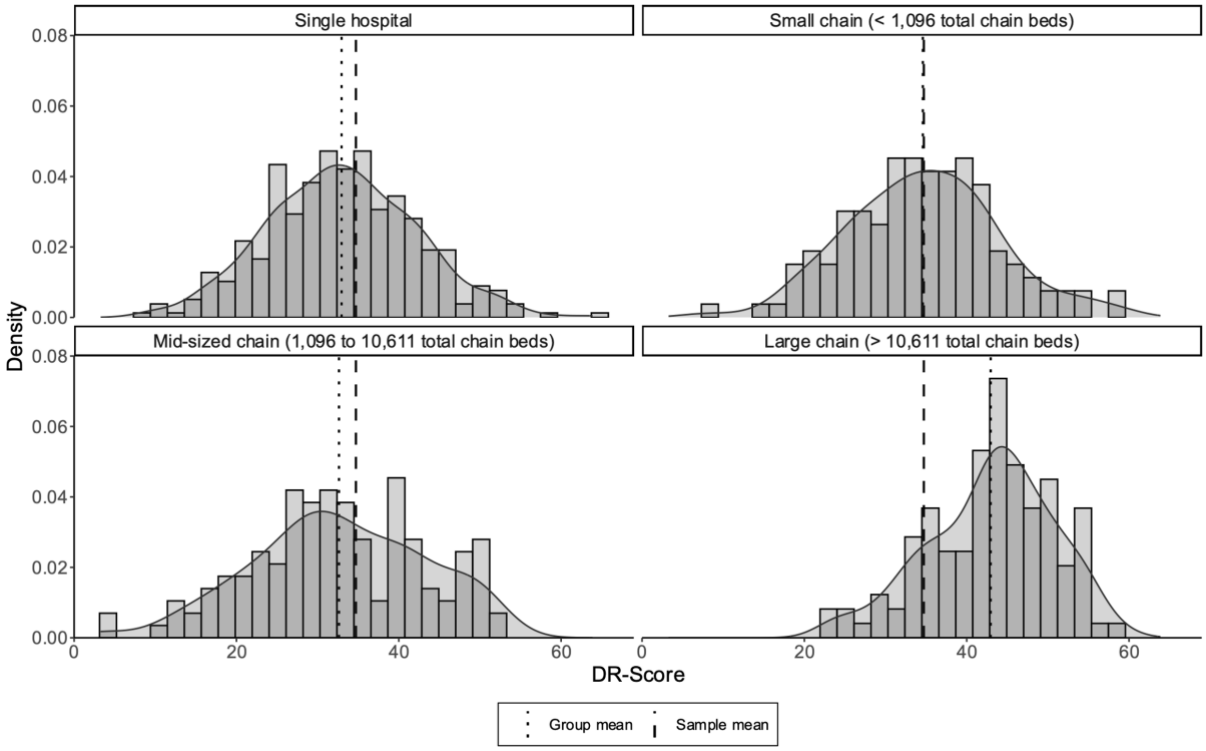
Descriptive statistics

We report descriptive statistics in Table 4 provided as supplementary material. The mean (median) EBITDA margin of our sample is at 5.2% (4.0%) with a relatively high standard deviation of 4.5%. Accordingly, the lowest EBITDA margin is at -16.3% and the highest at

18.5%. The mean (median) DR-score of our sample is 34.7 (34.6) points with 3.3 and 63.9 points being the minimum and maximum score reached. To understand the distribution of DR-scores better, we analyzed their frequency and density by chain size (see Figure 1).

Figure 1 shows the distribution of DR-scores for single hospitals and for chains according to terciles of their accumulated chain-level beds. The distribution of DR-scores is almost normal for single hospitals and small chains. DR-score means of the single hospital group, the small chain group, and the mid-sized chain group are all close to the sample mean and most hospitals have a DR-score of smaller than 40 points. Most hospitals that are part of a large chain, however, exhibit a DR-score of more than 40 points. Accordingly, the mean DR-score of the large chain group is much larger than the sample mean.

Figure 1: Frequency and density of DR-scores by chain size



Annotation: 375 hospitals are single hospitals, 127 hospitals are part of a small chain, 137 hospitals are part of a mid-sized chain, and 117 hospitals are part of a large chain. Small chains have less than 1,096 chain beds, mid-sized chains have between 1,096 and 10,611 chain beds, and large chains have more than 10,611 chain beds.

Regression results

Table 2 shows our main results. Overall, we conducted six regressions adding control variables or changing the set of control variables with each new regression to best approximate the profitability-digitization relationship.

The first, parsimonious regression model in column (1) shows a positive profitability-digitization relationship. The magnitude of the effect is small but highly statistically significant ($p<0.01$): A one percentage point increase in EBITDA margin is associated with an increase in the DR-score by 0.36 points. Put differently, an average hospital with a DR-score of 34.7 points might increase its DR-score by 1.0% with a one percentage point EBITDA margin increase. This one percentage point EBITDA margin increase is a relative increase of 19.4%, however, as hospitals' average EBITDA margin is at 5.2%.

Based on the distribution of DR-scores in Figure 1 and analyses in Table 3 (see supplementary material), we suspect that being part of a hospital chain may (positively) affect a hospitals' digital maturity. Thus, we present estimates of a model additionally controlling for a chain indicator in column (2). Moreover, we add standard county-level controls and federal-state-fixed effects. Indeed, we find a positive, highly statistically significant correlation between chain membership and digital maturity. On average, hospitals belonging to a chain score 3.09 points higher on the DR-score scale.

We investigate chain membership in more detail by interacting type of ownership with chain membership in regression (3). Compared to privately-owned single hospitals, the reference category, all permutations except nonprofit single hospitals achieve statistically significantly higher DR-Scores. Our main estimate of the correlation between the DR-score and the EBITDA margin stays consistent across the first three specifications.

However, once we control for chain size in regressions (4) and (5), the association between the EBITDA margin and DR-Score vanishes entirely. We use chain-level beds as a continuous control variable for chain size in regression (4). As the effect of being part of a chain may not evolve smoothly with the size of the chain, we separately investigate terciles of chain-level beds (regression 5).

Table 2: Main model results – dependent variable: DR-Score

DV: DR-Score	(1)	(2)	(3)	(4)	(5)
EBITDA margin	0.357***	0.354***	0.329***	0.044	0.050
	(0.108)	(0.111)	(0.113)	(0.107)	(0.107)
Base: Public ownership					
Private non-profit	-3.798***	-3.280***		-4.418***	-4.566***
	(0.814)	(0.841)		(0.788)	(0.789)
Private for-profit	-1.295	-2.845**		-10.845***	-10.180***
	(1.248)	(1.275)		(1.395)	(1.306)
Chain		3.092***			
		(0.731)			
Base: Single hospital * private for-profit					
Single hospital * public			5.535***		
			(1.967)		
Chain * public			8.373***		
			(2.084)		
Single hospital * private nonprofit			2.653		
			(1.880)		
Chain * private non-profit			4.308**		
			(1.890)		
Chain * private for-profit			6.441***		
			(1.892)		
Chain beds (in 100)				0.089***	
				(0.008)	
Base: single hospital					
Small chain					0.897
					(0.922)
Mid-sized chain					1.249
					(0.919)
Large chain					16.340***
					(1.435)
Hospital-level beds	Yes	Yes	Yes	No	No
County-level controls	No	Yes	Yes	Yes	Yes
Federal state dummies	No	Yes	Yes	Yes	Yes
Constant	29.288***	29.525***	24.980***	37.183***	36.898***
	(1.226)	(2.190)	(2.721)	(1.867)	(1.852)
N	756	756	756	756	756
R2 (adjusted)	0.125	0.159	0.163	0.223	0.240

Annotations: Dependent variable is the DR-score. Regression (1) shows a parsimonious specification with controls for ownership type, number of hospital beds and squared number of beds, (2) additionally includes a control for chain membership, as well as county-level controls (income tax and population density as terciles) and federal-state-fixed effects, (3) investigates interactions of ownership types and chain status, (4) and (5) controls for size of the chain by including the number of beds of the chain and terciles of chain-level beds, respectively. Small chains have in total less than 1,096 chain beds, mid-sized chains between 1,096 and 10,611 chain beds, and large chains more than 10,611 chain beds. Robust standard errors in parentheses. Asterisks indicate the significance level: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$.

This allows us to compare the impact of small (less than 1,096 chain beds), mid-sized (between 1,096 and 10,611 chain beds), and large chains (more than 10,611 chain beds) on hospitals' digital maturity. Our results suggest there is no effect of being in a small or mid-sized chain compared to single hospitals. However, we find that, on average, being part of a large chain is associated with a 16.340 points higher DR-Score. This large estimate might be explained by the fact that hospitals in the highest chain size tercile belong to the two largest privately-owned chains generally showing substantially higher DR-scores than the baseline category single hospitals (see also Figure 1).

4 Discussion

We are the first to analyze and present results on the association of hospitals' profitability and their digital maturity using a large sample of German hospitals. Our results are essential to understanding the (economic) dynamics of hospital digitization before effects of the Hospital Future Act's investment program could unfold. Thus, our findings are not only relevant for Germany but also beyond.

Concerning our first research question, whether a hospital's profitability is associated with its digital maturity, the answer is ambiguous. Generally, profitability seems to have a relatively small but highly statistically significant, positive influence on hospitals' digital maturity. However, when adding chain size controls, the influence of profitability vanishes.

Regarding our second research question, what other hospital characteristics are associated with hospitals' digital maturity, we clearly find that chain membership and especially chain size are of influence. This might be due to large chains benefiting from (1) a central IT strategy setting IT standards combined with strong strategy and project implementation, (2) a more

centralized IT infrastructure, enabling a more efficient and uniform rollout of digital systems and internal policies, and (3) cross-financing of projects between single hospital sites.

Building on the same argument of central IT strategy development and setting of standards, from a health system and hospital sector view, all hospitals might benefit from federal standards. Such standards could include requirement of interoperability using HL7-interface technology, in part also addressed as part of the Hospital Future Act.

Findings from the literature

A study from the United States investigates the effect of EHR adoption on different profitability measures using a hospital and year fixed effect model with a sample of 11,602 hospitals [19]. The authors measure digital maturity by defining three stages of EHR adoption (comprehensive, basic, and no adoption) based on the number of digitized clinical functions deployed in all units or at least one unit of a hospital. Profitability is measured with total margin, operating margin, and return on assets to receive a holistic picture of hospitals' financial situation. Indeed, the authors' research questions and hypotheses are not aiming at a profitability-digitization but a digitization-profitability relationship, i.e., they investigate whether stronger EHR adoption leads to higher profitability. The authors only find support for such a relationship for hospitals' total margin when using 2-year lagged data, i.e., digital maturity in the base year having financial effects two years later. According to the authors' findings, this relationship seems to be strongest for hospitals having no EHR to deploying a comprehensive EHR. In fact, the authors show that higher profitability is likely to be rather due to state-funded incentive payments for "meaningful use" of EHRs than optimized processes and cost structures. Overall, the study differs from ours mainly in that the investigated relationship is inverted, that digital maturity is measured differently, and that causal effects are investigated. Due to these differences, it is difficult to compare our results to

the study's results. Still, if focusing on the magnitude of the found relationship, the study's findings and our findings are comparable.

Limitations

As digital maturity has only been measured once across German hospitals, a causal relationship cannot be analyzed. Unveiling causal patterns, e.g., using a fixed effect model as in [19], will only be possible once additional longitudinal data on digital maturity will have been collected in 2024. Using fixed effect models with these new data should address reverse causality and simultaneity potentially present in our current data and approach. Moreover, they should confirm or rebut our interpretation regarding the dynamics of the relationship between profitability, chain size, and digital maturity.

Moreover, several databases needed to be linked to be able to include profitability and necessary controls in our analysis. Due to the necessary data matching, about 50% of the hospitals with digital maturity data could not be included in the analysis potentially creating selection bias. Still, we do not suspect that we exclude specific groups such as mostly (un-) profitable hospitals or mostly hospitals with a high (or low) DR-score.

5 Conclusions

Our results show that before the Hospital Future Act, it was mainly hospitals belonging to large chains that managed to digitize broadly.

In essence, the main implication for health policy makers thus is that our findings support the policy initiative of the Hospital Future Act. The corresponding investment program enables not only large chains to digitize but provides financial means to all German hospitals to digitize.

Sufficient financial means seem to be not the only necessary factor for hospital digitization, however. Large chain membership may also contribute to digitization as hospitals belonging to large chains can rely on central resources for IT-strategy development and implementation in addition to cross-financing. Thus, the main implication for single hospitals and small and mid-sized chains is that they should aim to centralize resources for IT strategy development and implementation. It has been common for hospitals for decades to organize in group purchasing organizations to bundle purchasing volume for medical technology and other needs with usually great results for most members. In the same spirit, it may be beneficial for hospitals to organize in and create similar organizations for IT needs.

Bibliography

1. Eichhorst S, Liese K, Moder S (2017) The Opportunities Offered by Digitizing Clinical Pathways. Service Business Model Innovation in Healthcare and Hospital Management 71–85. https://doi.org/10.1007/978-3-319-46412-1_5
2. Konsortium DigitalRadar (2022) Zwischenbericht - Ergebnisse der ersten nationalen Reifegradmessung deutscher Krankenhäuser
3. Stephani V, Busse R, Geissler A (2019) Benchmarking der Krankenhaus-IT: Deutschland im internationalen Vergleich. Krankenhaus-Report 2019 17–32. https://doi.org/10.1007/978-3-662-58225-1_2
4. Deiters W, Burmann A, Meister S (2018) [Strategies for digitalizing the hospital of the future]. Urologe A 57:1031–1039. https://doi.org/10.1007/S00120-018-0731-2
5. von Eiff MC, von Eiff W (2017) Perspektiven des IT-Managements im Gesundheitswesen. E-Health-Ökonomie 71–95. https://doi.org/10.1007/978-3-658-10788-8_5
6. Greß S, Heinemann S (2018) Germany: The Increasing Centralization of the Health Care Sector. In: Federalism and Decentralization in Health Care. University of Toronto Press, pp 71–89
7. Blümel M, Spranger A, Achstetter K, et al (2020) Germany: Health system review 2020. Health Syst Transit 22:1–272
8. Augurzky B, Schmitz H (2013) Wissenschaftliche Untersuchung zu den Ursachen unterschiedlicher Basisfallwerte der Länder als Grundlage der Krankenhausfinanzierung. Essen

9. Klein-Hitpaß U, Scheller-Kreinsen D (2015) Policy trends and reforms in the German DRG-based hospital payment system. Health Policy (New York) 119:252–257. https://doi.org/10.1016/J.HEALTHPOL.2015.01.006

10. Augurzky B, Krolop S, Hollenbach J, et al (2022) Krankenhaus Rating Report 2022. Heidelberg

11. van Poelgeest R, Schrijvers A, Boonstra A, Roes K (2021) Medical Specialists' Perspectives on the Influence of Electronic Medical Record Use on the Quality of Hospital Care: Semistructured Interview Study. JMIR Hum Factors 8:e27671. https://doi.org/10.2196/27671

12. van Poelgeest R, Heida JP, Pettit L, et al (2015) The Association between eHealth Capabilities and the Quality and Safety of Health Care in the Netherlands: Comparison of HIMSS Analytics EMRAM data with Elsevier's "The Best Hospitals" data. J Med Syst 39:90–90. https://doi.org/10.1007/S10916-015-0274-7

13. van Poelgeest R, van Groningen JT, Daniels JH, et al (2017) Level of Digitization in Dutch Hospitals and the Lengths of Stay of Patients with Colorectal Cancer. J Med Syst 41:1–7. https://doi.org/10.1007/S10916-017-0734-3

14. Bundesamt für Soziale Sicherung (2021) Richtlinie zur Förderung von Vorhaben zur Digitalisierung der Prozesse und Strukturen im Verlauf eines Krankenhausaufenthaltes von Patientinnen und Patienten nach § 21 Absatz 2 KHSFV. Bundesministerium für Gesundheit Deutschland, Germany

15. Bureau van Dijk (2021) Dafne database - German company data & financials. https://www.bvdinfo.com/en-gb/our-products/data/national/dafne. Accessed 17 Mar 2022

16. Statistisches Bundesamt (2020) Verzeichnis der Krankenhäuser und Vorsorge- oder Rehabilitationseinrichtungen in Deutschland 2020. Wiesbaden

17. Bundesinstitut für Bau- SR (2022) Datenprodukt: INKAR – Indikatoren und Karten zur Raum- und Stadtentwicklung. https://www.inkar.de/. Accessed 3 May 2022

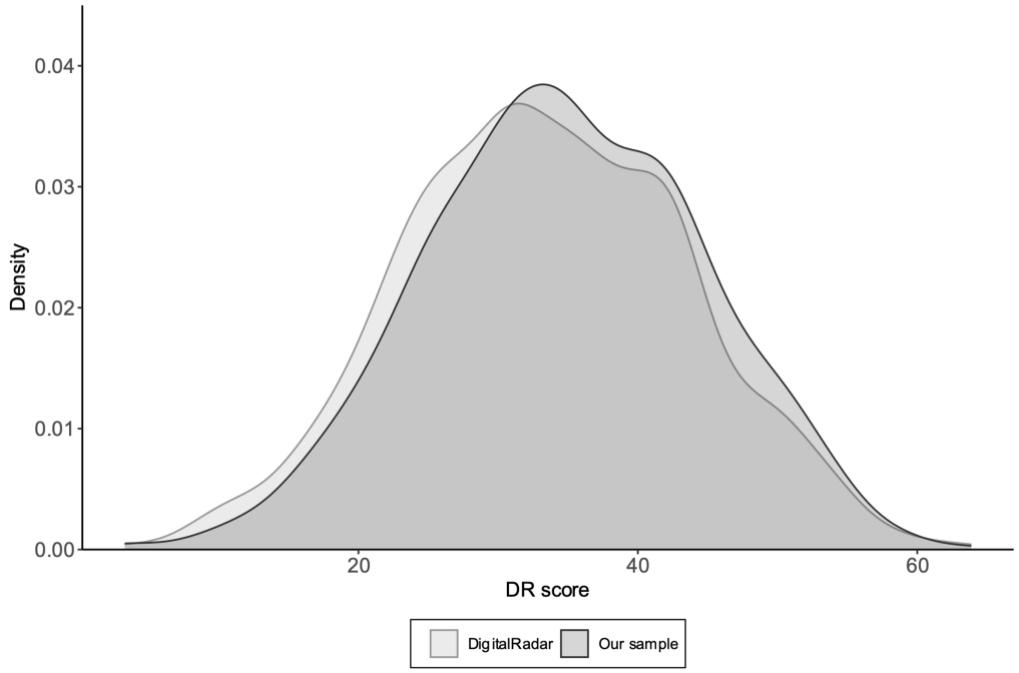
18. Augurzky B (2020) Gewinne im Krankenhaus. In: Klauber J, Geraedts M, Friedrich J, et al (eds) Krankenhaus-Report 2020. Springer, Berlin, Heidelberg, pp 185–204

19. Collum TH, Menachemi N, Sen B (2016) Does electronic health record use improve hospital financial performance? Evidence from panel data. Health Care Manage Rev 41:267–274. https://doi.org/10.1097/HMR.0000000000000068

Supplementary Material

A-1 Distribution of DC-scores in our sample vs. the DR sample

Figure 2: Distribution of DR-scores



Data sources: DigitalRadar [2], own calculations

A-2 Descriptive statistics by chain size to identify relevant control variables

Table 3: Summary by chain size

	Single hospital			Small chain			Mid-sized chain			Large chain			p-value
Variable	N	Mean	SD	N	Mean	SD	N	Mean	SD	N	Mean	SD	
DR-score	375	32.95	9.12	127	34.59	9.28	137	32.63	10.69	117	42.95	7.70	< 0.001
EBITDA margin	375	4.12	4.36	127	3.86	4.51	137	4.42	2.52	117	10.78	1.58	< 0.001
Beds, in 100s	375	3.23	2.36	127	2.88	2.00	137	3.48	2.32	117	2.82	2.34	0.023
Chain beds, in 100s	375	3.23	2.36	127	6.39	2.77	137	43.57	36.09	117	173.96	48.71	< 0.001
Ownership	375			127			137			117			< 0.001
Public	130	34.7%		59	46.5%		34	24.8%		0	0%		
Nonprofit	202	53.9%		57	44.9%		54	39.4%		0	0%		
Private	43	11.5%		11	8.7%		49	35.8%		117	100%		
Chain membership	375			127			137			117			< 0.001
Not in a chain	375	100%		0	0%		0	0%		0	0%		
Part of a chain	0	0%		127	100%		137	100%		117	100%		
Income tax level	375			127			137			117			0.140
Lowest	110	29.3%		45	35.4%		48	35.0%		49	41.9%		
Middle	133	35.5%		40	31.5%		50	36.5%		29	24.8%		
Highest	132	35.2%		42	33.1%		39	28.5%		39	33.3%		
Population density	375			127			137			117			< 0.001
Lowest	116	30.9%		37	29.1%		39	28.5%		60	51.3%		
Middle	135	36.0%		47	37.0%		42	30.7%		28	23.9%		
Highest	124	33.1%		43	33.9%		56	40.9%		29	24.8%		

Annotations: We conducted Kruskal-Wallis rank sum tests for continuous variables and Pearson's Chi squared tests for binary variables.

A-3 Descriptive statistics of entire hospital sample

Table 4: Descriptive statistics

Variable	N	Mean	Std. Dev.	Min	Median (IQR)	Max
DR-score	756	34.72	9.91	3.27	34.60 (14.08)	63.87
Single hospitals	375	32.95	9.12	8.98	32.75 (13.06)	63.87
Small chains	127	34.59	9.28	7.77	34.58 (12.13)	58.97
Mid-sized chains	137	32.63	10.69	3.27	32.22 (14.48)	51.52
Large chains	117	42.95	7.7	23.69	43.82 (10.68)	58.98
EBITDA margin	756	5.16	4.49	-16.33	4.88 (5.41)	18.45
Single hospitals	375	4.12	4.36	-16.33	3.96 (4.07)	18.45
Small chains	127	3.86	4.51	-9.81	3.52 (5.75)	14.28
Mid-sized chains	137	4.42	2.52	-0.14	4.88 (5.03)	7.35
Large chains	117	10.78	1.58	8.89	12.09 (3.21)	12.09
Beds, in 100s	756	3.152	2.30	0.20	2.55 (2.96)	11.81
Single hospitals	375	3.23	2.36	0.20	2.61 (2.94)	11.81
Small chains	127	2.88	2.00	0.31	2.41 (2.4)	10.42
Mid-sized chains	137	3.48	2.32	0.46	3.00 (3.31)	10.65
Large chains	117	2.82	2.34	0.34	2.09 (2.42)	11.50
Chain beds, in 100s	756	37.493	65.13	0.20	5.5 (25.73)	214.41
Single hospitals	375	3.23	2.36	0.20	2.61 (2.94)	11.81
Small chains	127	6.39	2.77	0.34	6.66 (4.43)	10.50
Mid-sized chains	137	43.57	36.09	10.96	31.15 (17.69)	106.11
Large chains	117	173.95	48.71	115.80	214.41 (98.61)	214.41