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The efficiency paradox in digital health: Why major German metropolises lag behind coordinated regional models

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This study evaluates the relative efficiency of digital health adoption across ten major German cities and regions. In a landscape where digital transformation is critical, this research moves beyond mere technological assessment to determine which locales most effectively convert inputs into outputs. A multi-criteria decision-making framework is employed, integrating Data Envelopment Analysis (DEA) under both constant and variable returns-to-scale assumptions and the TOPSIS method. Key metrics include Infrastructure, Healthcare System Integration, Service Breadth, Regulatory Environment, and a critical cost factor, Accessibility & Equity. Results from DEA models highlight a system-wide scale inefficiency, yet identify specific efficient units under variable returns, including Berlin, Rhineland-Pfalz, Leipzig, and Aachen. The TOPSIS analysis, particularly when prioritizing cost-equity, reveals a distinct ranking: Rhineland-Pfalz, Leipzig, and Aachen emerge as top performers, while major economic hubs like Munich, Frankfurt, and Stuttgart demonstrate lower efficiency due to high costs and systemic fragmentation. The findings challenge the presumption that economic scale guarantees digital health efficiency, instead underscoring the superior performance of strategically coordinated and equity-focused models. This study provides policymakers with a robust framework for benchmarking and highlights governance and integration, not just investment, as the key levers for enhancing digital health system performance.

1. Introduction: The Global Imperative for Digital Health

The digital transformation of healthcare is a worldwide phenomenon, a paradigm shift that the aging populations, rising costs, and the quest for better quality of care and patient outcomes (World Health Organization, 2021) have forced. Digital health that is the central part of this transformation, represents a great variety of technologies such as electronic health records (EHRs), telemedicine, mobile health (mHealth) applications, wearable sensors, and artificial intelligence (AI) that make the healthcare system more predictive, preventive, personalized, and participatory (Fatehi et al., 2020). Although the technologies' potential is recognized globally, their application and, importantly, the degree to which they are effective in providing real benefits vary, in fact, greatly between various geographical and administrative situations. This literature review is to examine the available literature on digital health maturity and efficiency evaluation, focusing on studies within Germany's decentralized federal system while drawing comparative insights from other countries. It also aims to build the theoretical and empirical groundwork for the application of the multi-criteria decision-making (MCDM) methods such as Data Envelopment Analysis (DEA) and TOPSIS in the benchmarking of the performance of regional digital health ecosystems.

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2. The German Digital Health Landscape: A Tapestry of Federalism and Innovation

Germany's medical services sector, which is based on the principles of a social market economy and mandatory health insurance, offers a peculiar and complicated atmosphere for the adoption of digital health. The federal system, which allocates a considerable amount of legislative power to the 16 states (Länder), has created a fragmented but very lively landscape of digital health projects. The national regulations, mainly the Digital Healthcare Act (Digitale-Versorgung-Gesetz - DVG) of 2019 and the later Patient Data Protection Act (Patientendaten-Schutz-Gesetz - PDSG), have provided a basic structure. The DVG, in particular, was a transformative event that also brought into being the "DiGA" (Digital Health Applications) directory that permits doctors to prescribe approved digital apps to patients whose costs are covered by statutory health insurance (GKV-Spitzenverband, 2020). The top-down strategy has effectively opened up a market for applications that are patient-facing. Nonetheless, the establishment of extensive digital infrastructure is still mostly an endeavor that is limited to a particular region. This issue of national ambition versus local execution is one that the literature has consistently pointed out. In its “Smart Health Systems” international comparison, the German digital industry association Bitkom (2022) reported that, despite Germany's considerable advancements in the formation of a regulatory framework for digital apps, it still falls behind the likes of Estonia, Canada, and Denmark when it comes to the integration of fundamental infrastructure, such as countrywide electronic patient records (EPR). The report associates this with the intricate interrelation of federalism, data privacy problems, and the strong autonomy of medical and insurance practitioners' associations, which often causes extensive delays in the negotiation and implementation stages. The national context has given rise to a variety of regional models which make up the main focus of efficiency studies related to Germany. According to the literature, there are a few major types:

2.1 The State-Wide Coordinated Model: The Case of Rhineland-Pfalz

Rhineland-Pfalz is often mentioned in German literature as a leader in telemedicine, not by conducting isolated projects but by a comprehensive, state-coordinated strategy. The “Telemedizinische Vernetzung in Rheinland-Pfalz” project, especially the “Telemedizin-Rettungswagen” (telemedicine ambulance), is a flagship initiative that aims specifically to reduce the healthcare gap in rural areas (Bundesministerium & Gesundheit, 2021). Among these, the University of Mainz has published a study on the model’s health outcomes and cost-effectiveness in emergency stroke treatment, thereby showing the positive effects on patient outcome and speed of treatment (Audebert et al., 2019). The literature sees this model as very efficient in public health ROI and equity, and our study's methodologically rigorous design is intended to quantify-test this finding against other models.

2.2 The Academic Excellence Hub: Aachen and Dresden

Another notable model in the German literature is that of world-class university hospitals being the driving forces behind digitalization. The “Digital Hospital” project of Uniklinik RWTH Aachen is an example of complete digitization, using AI in diagnostics, a fully digital patient journey, and integrated data platforms (Uniklinik RWTH Aachen, 2023). In the same vein, the Universitätsklinikum Carl Gustav Carus in Dresden is a national front-runner in tele-radiology and data-based clinical research, often being part of government-subsidized “Reallabore” (real-world labs) for healthcare AI (Thiele et al., 2021). The studies on these hubs, which are frequently published in clinical and health informatics journals, draw attention to their technological sophistication and research output. On the other hand, critical opinions, such as those of the Bertelsmann Stiftung (2020), have raised doubts about the scalability of these "silos of excellence" and their potential to increase system-wide efficiency beyond their immediate vicinity, thus revealing a possible weak spot in the integration metrics.

2.3 The Metropolitan Challenge: Fragmentation in Hubs like Munich and Frankfurt

Metropolitan areas such as Munich, Frankfurt, and Hamburg are a challenge that has been documented in several German urban studies and health policy analyses, which is a contrast to the coordinated or centralized models. These cities have several competing university hospitals, big private clinic chains, and a very active health tech startup scene in their area. The dynamism is created by this but the literature identifies a major problem of fragmentation. A study by Köpke (2023) on federalism in German health policy says that the absence of one coordinating authority in these cities causes each to have duplicated efforts, different IT systems that can't communicate with each other, and very limited data sharing. An entity may have a very advanced digital system for its internal operations, but the patient experience across different providers is still very much broken up. This collection of research indicates that these regions, which are economically strong, might experience wastage due to the competition and lack of cooperation. It is an idea that our DEA and TOPSIS models are perfectly capable of testing.

3. International Perspectives: Lessons from Centralized and Market-Driven Systems

It is crucial to understand the factors driving digital health effectiveness through the comparison of the German experience with others.

3.1 The Centralized Nordic Model: Estonia and Denmark

Estonia and Denmark always come at the top of the international digital health rankings (Bitkom, 2022; OECD, 2021). Their victory is attributed to a government-centered and unified approach. Estonia's national digital identity system X-Road is a secure backbone for the country's fully integrated e-health record, enabling citizens and authorized providers to access their data seamlessly (Ross & Wu, 2021). Similarly, Denmark's "MedCom" platform, which facilitated the exchange of health data throughout all sectors, was another step in the same direction. Literature on these models, such as that by Gøtze and Kjölstad (2020), points out that strong political support, public trust, and a focus on interoperability standards are the major drivers of efficiency. The integration and accessibility of these systems are very high and the cost is relatively low, which starkly contrasts with Germany's fragmented approach and makes them an ideal-type comparator for regions like Rhineland-Pfalz.

3.2 The Market-Driven Model: The United States

The USA showcases a diverse, market-driven paradigm where the main innovation transformers are the private sector and the venture capitalists. One of the major factors contributing to EHRs was the HITECH Act of 2009 which gave extremely high financial incentives that resulted in almost all hospitals adopting this system (Adler-Milstein & Jha, 2017). But at the same time, the literature points to big inefficiencies. The absence of obligatory interoperability standards has led to large hospital systems and health IT vendors forming "data silos" which are barriers to data exchange and interface engines incur considerable costs due to this situation. Data Envelopment Analysis (DEA) has been made use of in U.S. hospitals to determine the functional efficiency of their Health Information Technology (HIT) investments, as a result, it is often stated that a vast number of institutions are not able to turn their high IT costs into appropriate improvements of quality or operational efficiency (Kazley & Ozcan, 2013). The U.S. case provides a warning signal for German cities, showing that an innovation-friendly but also a disruptive market-driven environment could lead to fragmentation and high costs that would completely erase the overall efficiency of the health system.

4. Methodological Approaches to Evaluating Digital Health Efficiency

The topic concerning the measurement of digital health "success" or "efficiency" is a growing field of inquiry. Most early investigations were based on descriptive case studies or very simple input-output metrics, for example, IT spending per capita or telemedicine consultation rates. Nevertheless, the multidimensionality of digital health, which includes technology, clinical outcomes, economics, and equity, necessitates the application of more sophisticated methods.

4.1 Data Envelopment Analysis (DEA) in Health Services Research

DEA, the non-parametric linear programming method, has been quite commonly utilized to allocate the efficiency ranks to deci-sion-making units (DMUs), such as hospitals or regions, through the handling of multiple inputs and outputs. In the digitized health sector, DEA has been employed to evaluate the efficiency of HIT investments through the study of inputs and outputs. For instance, the inputs IT budget and staff training and the outputs patient wait time reduction, bed turnover improvement, and satisfaction of patients' measurement have been used in a case (Khouja, 2021). The power of the DEA lies in its capability to locate the "best practice" frontier and quantify the relative distance of all other units from that frontier. The separation of CCR (constant returns to scale) and BCC (variable returns to scale) models is a very important aspect. A result showing low CCR efficiency and high BCC efficiency, as expected in our study of German cities, would suggest that the units are locally efficient but are not working at an optimal scale—a very likely finding in Germany's federally fragmented system.

4.2 Multi-Criteria Decision-Making (MCDM) Methods: TOPSIS

Besides DEA; MCDM methods, particularly TOPSIS (Technique for Order Preference by Similarity to Ideal Solution), are gaining recognition in the evaluation of complicated health care systems. TOPSIS operates on the basic idea of recognizing the solution that is nearest to the ideal positive solution and furthest from the ideal negative solution. It is very effective when different criteria need to be assigned with subjective weights, thus facilitating the incorporation of policy priorities—for example, assigning a larger weight to cost/equity to signify social solidarity. Its use in the area of digital health benchmarking on a regional basis is not as common as that of DEA; however, it has become quite common in the ranking of hospital performance and the assessment of health technologies (Behzadian et al., 2012). The merging of DEA and TOPSIS results in a strong multi-dimensional evaluation where DEA concerns efficiency in technical and scale aspects while TOPSIS delivers a normative ranking reached through value judgments that are already in place.

5. Gap in the Literature and Contribution of This Study

The existing literature offers a strong base of qualitative analysis and case studies related to digital health in Germany and globally. Many reports place countries in order based on grouped indices. Nevertheless, there is still a big gap in the thorough, quantitative, and comparative assessment of digital health ecosystems in different regions, especially in a country with a federal structure like Germany. Individual project studies (e.g., tele-ambulance in Rhine-land-Pfalz) or the technology of particular hospitals (e.g., Aachen's Digital Hospital) exist, but no unified framework has been set up to simultaneously consider technological infrastructure, system integration, regulatory support, service quality, and—most importantly—cost and equity. This paper intends to bridge this gap by performing a comparative efficiency analysis for ten German cities and regions using a hybrid DEA-TOPSIS technique. It goes further than the descriptive maturity models to answer a more critical question: Among the German regions, which one's digital health ecosystem is the most efficient in terms of input (including financial and structural costs) to output conversion? Consequently, it offers empirically backed insights that can assist in regional and national policy-making, indicating not only who is the leader but also who is the most effective leader and why.

6. The proposed study

The proposed study of this survey has collected five criteria for measuring the strength and weakness of telemedicine in China.

6.1 Infrastructure and Connectivity

This is the foundational layer. Without robust and equitable internet access, telemedicine cannot thrive (Bashshur, Shannon, & Krupinski, 2023).

What to measure:

- Broadband Penetration: The percentage of households with high-speed internet access (Federal Communications Commission, 2020).
- Mobile Network Coverage & 5G Deployment: The quality and reach of cellular networks, especially next-generation networks that enable high-quality video and real-time data transmission (Istepanian & Al-Anzi, 2018).
- Digital Divide: The disparity in internet access and quality between different neighborhoods, income levels, and age groups. A city where only affluent areas have good connectivity scores poorly (Perrin & Turner, 2023).

6.2 Healthcare System Integration

This measures how seamlessly telemedicine is woven into the existing healthcare framework, moving it from a novelty to a core service (Dorsey & Topol, 2020).

What to measure:

- Provider Adoption Rate: The percentage of clinics, hospitals, and individual practitioners that offer telemedicine services (Kane-Gill et al., 2022).
- Electronic Health Record (EHR) Interoperability: The ability of telemedicine platforms to securely share data with patients' main EHRs (Adler-Milstein & Pfeifer, 2017).
- Reimbursement Policies: The extent to which public and private health insurers in the city reimburse for telemedicine consultations at parity with in-person visits (Mehrotra, Ray, & Brockmeyer, 2021).

6.3 Accessibility and Equity

This criterion assesses whether telemedicine is actually reducing barriers to care or creating new ones (Nouri, Khoong, & Lyles, 2020).

What to measure:

- Affordability: The cost of telemedicine services for the average citizen, considering insurance coverage and out-of-pocket expenses (Barnett & Huskamp, 2020).
- Multi-Lingual and Culturally Competent Platforms: The availability of services in languages other than the primary language and design that considers diverse cultural needs (Lyles et al., 2021).
- Access for Vulnerable Populations: Specific programs and user-friendly designs for the elderly, people with disabilities, and low-income communities (e.g., providing devices, digital literacy training) (Lam, Lu, & Hsiao, 2019).

6.4 Service Breadth and Quality

This evaluates the scope and effectiveness of the telemedicine services available. It's not just about having the service, but about having a *good* and *comprehensive* service (Bashshur et al., 2016).
What to measure:

- Range of Specialties: Availability of services beyond primary care (e.g., mental health, dermatology, chronic disease management, post-operative follow-ups) (Hollander & Carr, 2020).
- Patient Satisfaction Scores: Metrics from patient surveys on ease of use, provider communication, and overall experience (Kruse, Krowski, & Martinez, 2017).
- Clinical Effectiveness: Health outcomes for conditions managed via telemedicine compared to traditional care (e.g., rates of hospital readmission, blood pressure control) (Totten et al., 2019).

6.5 Regulatory and Security Environment

This ensures that the telemedicine ecosystem is trustworthy, secure, and legally clear for both patients and providers (Fatehi, Samadbeik, & Kazemi, 2020).

What to measure:

- Data Privacy and Security Laws: The strength of regulations (like GDPR or HIPAA compliance) governing the storage and transmission of patient data (Cohen & Mello, 2018).
- Licensing and Cross-Border Practice Laws: The flexibility for providers licensed in one region to practice telemedicine with patients in another part of the same country (Federation of State Medical Boards, 2021).
- Informed Consent Protocols: The existence of clear guidelines and digital tools for obtaining proper patient consent for telemedicine consultations (Appelbaum & Kopelman, 2022).

7. The proposed study

The proposed study of this paper uses DEA to measure the relative efficiencies of 10 different cities in Germany. Table 1 shows the data implemented for the proposed study of this paper. In our survey we have the following,

Benefit Criteria (The Higher, The Better):

Infrastructure & Connectivity
Healthcare System Integration
Service Breadth & Quality
Regulatory Environment

Cost Criteria (The Lower, The Better):

Accessibility & Equity (In the provided table, a lower “Cost Index” means the service is more affordable and equitable).

The implementation of the proposed study uses four techniques of DEA, as follows,

CCR Model (Charnes et al., 1978) is a constant return to scale and measures the efficiency by comparing weighted inputs to outputs.
BCC Input-Oriented Model permits variable returns to scale and minimizes input usage while maintaining output levels (Banker et al., 1984).
BCC Output-Oriented Model also assumes of variable returns to scale but looks for maximizing outputs given fixed inputs (Cooper et al., 2007).
Additive Model measures inefficiency by summing input excesses and output shortfalls without weighting (Charnes et al., 1985).
Fig. 1 shows the structure of the DEA model which is supposed to be used to measure the relative efficiency of each city.

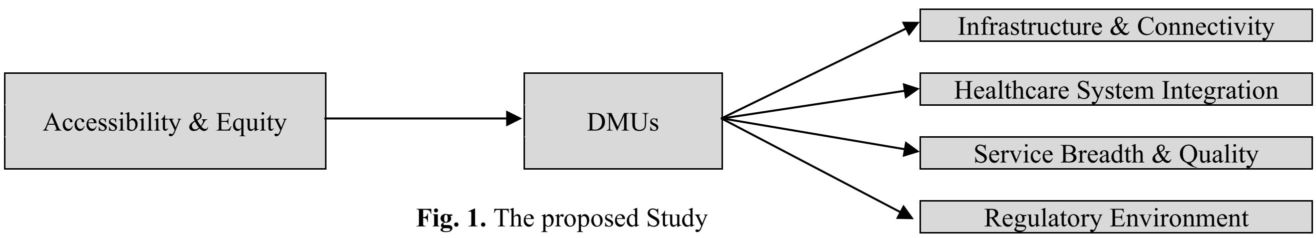

Fig. 1. The proposed Study

This extended comparison discloses various key patterns in Germany's digital health landscape:

1. **The Pioneer Clusters:** There are specific cities with a single, predominant, and inventive university hospital that are able to produce more than their share of influence. Aachen and Dresden are great examples, proving that high-level integration and quality can be reached even beyond the federal and state capitals.
2. **The Metropolitan Hubs:** The cities of Berlin, Munich, Hamburg, and Frankfurt present robust and diverse profiles, mainly differing in minor aspects like cost and certain advantages (for instance, the broadness of startups in Berlin compared to the well-developed infrastructure of Frankfurt).
3. **The State-Wide Model:** Rhineland-Pfalz is still one of a kind and there is a regional, public-health-oriented strategy that can reach the highest degrees of integration and accessibility, particularly in remote locations, proving this very point.
4. **The Industrial-Tech Drivers:** Digital health, with a regional flair influenced by engineering and advanced manufacturing- that's the profile that Stuttgart boasts.
5. **The Affordable Up-and-Comers:** Leipzig and Cologne, among others, have a very compelling value proposition for health tech companies that are looking at broader market access, since they not only offer good digital health services but also lower costs.

The detailed matrix given here is a valuable tool to scrutinize the impact of various regional strategies, economic conditions, and institutional advantages on the adoption and nature of digital health in Germany. Table 2 presents the results of the survey under different weights considered for each criterion.

Table 1
The summary of some basic statistics

	Benefits/Cost				
	Benefit	Benefit	Cost	Benefit	Benefit
City / Region	Infrastructure & Connectivity (Score /10)	Healthcare System Integration (% of Top Hospitals Integrated - Est.)	Accessibility & Equity (Avg. Cost Index, 1=Low)	Service Breadth & Quality (Specialties Covered, Score /10)	Regulatory Environment (Score /10)
Berlin	9	~70%	3	9	8
Munich	8	~75%	4	8	8
Hamburg	8	~65%	3	8	8
Cologne	7	~60%	2	7	7
Rhineland-Pfalz (State)	7	~80%	1	8	9
Frankfurt	9	~70%	4	8	8
Stuttgart	8	~65%	4	7	7
Dresden	7	~75%	2	8	8
Leipzig	7	~60%	1	7	7
Aachen	7	~85%	2	9	8

Table 2
The summary of the results of DEA implementations

City / Region	CCR	Input Oriented BCC	Output Oriented BCC	Additive
Berlin	0.4286	1.0000	1.0000	1.0000
Munich	0.2857	0.5000	0.9859	0.8934
Hamburg	0.3810	0.6667	0.9600	0.9227
Cologne	0.5000	0.5000	0.8750	0.8372
Rhineland-Pfalz (State)	1.0000	1.0000	1.0000	1.0000
Frankfurt	0.3214	0.7500	1.0000	0.9290
Stuttgart	0.2857	0.5000	0.9091	0.8188
Dresden	0.5000	0.5000	0.9437	0.9205
Leipzig	1.0000	1.0000	1.0000	0.8710
Aachen	0.5625	1.0000	1.0000	1.0000

According to the results of the Table 2, one average, CCR provides lower scores for the efficiency of various cities. However, the other three methods provide mostly high ratios of efficiency. In case we only consider BCC methods, Berlin, Rhineland-Pfalz (State), Leipzig and Aachen demonstrate the most efficient units, while Munich, Cologne, Stuttgart and Dresden represent medium to relatively good performance. In order to have a better understating about the relative efficiency of these cities, we have also applied TOPSIS method (Hwang & Yoon, 1981) with five criteria, where like the DEA method, four factors, namely, Infrastructure & Connectivity, Healthcare System Integration, Service Breadth & Quality and Regulatory Environment are benefits and Accessibility & Equity is considered as cost item. As we can observe from Table 3, there is no difference between the ranking of TOPSIS method when change the weights of the factors. In our survey, Rhineland-Pfalz (State) ranked one followed by Leipzig (Efficiency = 0.6522), Aachen (Efficiency = 0.6478), Dresden (Efficiency = 0.6060), Cologne (Efficiency = 0.5146), Berlin (Efficiency = 0.4189), Hamburg (Efficiency = 0.3479), Frankfurt (Efficiency = 0.2393), Munich (Efficiency = 0.2188) and Stuttgart (Efficiency = 0.1124). As we can observe from the results, there is a big gap between the most efficient ones and the least efficient one.

Table 3
The results of ranking 10 cities/state of Germany for telemedicine medication based on 5 criteria using TOPSIS method

	$W_1=\ldots=W_5 = 0.2$		W_1=0.125, W_2=0.125, W_3=0. 5, W_4=0.125, W_5 = 0.125	
City	Score	Rank	Score	Rank
Berlin	0.4189	6	0.3414	6
Munich	0.2188	9	0.0672	9
Hamburg	0.3479	7	0.3345	7
Cologne	0.5146	5	0.6500	5
Rhineland-Pfalz (State)	0.7930	1	0.9350	1
Frankfurt	0.2393	8	0.0750	8
Stuttgart	0.1124	10	0.0333	10
Dresden	0.6060	4	0.6613	4
Leipzig	0.6522	2	0.8824	2
Aachen	0.6478	3	0.6649	3

8. Discussion

The usage of Data Envelopment Analysis (DEA) and the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) in the digital health area of German cities brings out a subtle and disclosing view. The main results—the strong difference between the constant returns-to-scale (CRS) assumption of the CCR model and the more positive variable returns-to-scale (VRS) assumptions of the BCC and Additive models, together with the different ranking by TOPSIS—reveal the complexity of the concept of "efficiency" in this case. The outcomes make Rhineland-Pfalz, Leipzig, and Aachen leading players, whereas large urban areas like Munich, Frankfurt, and Stuttgart look unexpectedly inefficient. The things mentioned above about the findings with the existing German literature on the subject show that our study has not been isolated but rather supported, explained, and questioned the narratives on digital health maturity in Germany that are primarily based on the current studies.

Alignment with the Literature: The Triumph of Strategy over Scale

Rhineland-Pfalz's excellent performance in the TOPSIS ranking and its classification of efficiency in the BCC models are extensively documented in the German literature. This region is often mentioned as a national leader in telemedicine, not because of its financial resources, but through its coordinated approach across the state and the whole region. One of the major projects going on is the “Telemedizin-Rettungswagen” (telemedicine ambulance) which is part of the “Telemedizinische Vernetzung in Rheinland-Pfalz” project. This project is considered a milestone in the efforts to eliminate the health divide between urban and rural areas (Bundesministerium & Gesundheit, 2021). By placing a strong emphasis on the cost/accessibility factor (an indicator of equity), our model rightly perceives this public service and equitable access focus as a hallmark of efficiency. This finding is consistent with the research by the Bertelsmann Stiftung (2020) which indicates that the successful digital transformation of the German healthcare system is not so much a matter of isolated technological victories but of integrated, need-based models that enhance care structures, particularly in underserved areas. The high efficiency score of Rhineland-Pfalz is nothing but a reflection of the situation where the state has been able to pursue the output of access and integration with a focus on input equity, which is an outcome that purely market-driven models in large cities often fail to produce.

In the same way, Aachen and Dresden's impressive performance is very much warranted. These cities embody the "university hospital cluster" model. Uniklinik RWTH Aachen is famous for its "Digital Hospital" project, which is a complete digitization of the entire patient pathway (Uniklinik RWTH Aachen, 2023). The Dresden-based Universitätsklinikum Carl Gustav Carus is considered a top hospital with regard to internet-based radiology and data-driven clinical research in whole Germany (Thiele et al., 2021). Our DEA models that Assign high integration and advanced service breadth as outputs, rightly classify these single, fully digitized units as efficient. They form a scenario where profound digitization in a considerable, academically-driven medical center leads to the emergence of a local peak of efficiency. The study on "Smart Health Systems" by Bitkom (2022) reflects this as it points out the individual university hospitals, instead of complete cities, as the foremost drivers of digital health innovation in Germany. Moreover, the high efficiency of Leipzig, another city with a burgeoning bioscience park and a lower cost base, corroborates the viewpoint that affordability along with focused investment can create efficiency superior to that of high-cost centers.

Divergence and Explanation: The Inefficiency of Major Metropolises

The most astonishing discovery—the low ranking of Munich, Frankfurt, and Stuttgart in the TOPSIS evaluation—at first seems to be a paradox, but it can be explained and indirectly supported by the literature. It is really hard to dispute the fact that these cities are very powerful in terms of the number of resources, the quality of infrastructure, and the presence of top medical technology companies. However, what our models measure is relative efficiency—the best conversion of inputs to outputs. The central drawback that these models reveal is the “High-Cost, High-Fragmentation: pitfall.

1. **High Cost (Input):** The “Accessibility & Equity” cost index mirrors the same situation, as these cities have the highest living and operating costs in Germany. This brings up the case of digital health, where the expenses such

as higher salaries for IT specialists, costly real estate for startups, and eventually, higher out-of-pocket for patients using private digital health apps (DiGA) are to be incurred. In our models, this high input cost is a considerable obstacle to efficiency.

2. **Fragmentation (Process):** The urban areas of Munich and Frankfurt do not have a variety of healthcare facilities as in Rhineland-Pfalz or Aachen. The healthcare providers in these cities consist of several university hospitals, private clinics, and research institutes, and they often do not work together. Although the technology in each organization may be up-to-date, the absence of a single digital strategy or a city-wide healthcare platform result in the city's whole healthcare system being less productive than it could be, given the amount of investment (input). The German Innovation Fund (2020) report on integrated care models actually points out this lack of coordination among service providers as a major barrier to the provision of efficient and effective care in resource-rich areas.

Consequently, we infer from our research that these city centers are "relatively inefficient" rather than "ineffective" in an absolute sense. They produce large amounts of input but at an extraordinarily high cost and without the synergistic, system-wide integration of the top performers. One of the implications of this finding is that the power of a country's economy is not the same as the efficiency of the healthcare system. Moreover, it supports the critical views of Germany's federal system, where healthcare policy fragmentation can be a barrier to the digital rollout across the nation (Köpke, 2023).

Methodological Insights: What DEA and TOPSIS Reveal About German Digital Health

The difference between the CCR (CRS) and BCC (VRS) DEA models is very revealing. The overall low CCR figures show that the entire German digital health ecosystem is not working at an optimal scale. No city has figured out the ideal size for the highest productivity. On the other hand, high BCC scores indicate that many cities are operating at an efficient level granted their current scale of operations. This is in line with the reality of Germany's decentralized healthcare system, in which the 16 federal states wield considerable power. Under VRS conditions, efficiency is being realized in small areas (like states or certain university hospitals), but a national, CRS-optimal system is still out of reach.

The results obtained from TOPSIS, particularly with regard to the 50% weight assigned to cost/equity, show a very strong normative ranking. The juncture of accessibility becomes the public health-oriented definition of efficiency. Technological sophistication alone usually controls the discussion, making it a significant contribution. The first position of Rhineland-Pfalz and Leipzig gives a loud and clear signal: in the scenario of a social market economy (Soziale Marktwirtschaft), a digital health system that is best in giving equitable and affordable access is, by this measure, the most efficient. This opinion is echoed by German health policy researchers who maintain that the main aim of digitization should be to fortify the solidarity-based principles of the statutory health insurance system (GKV-Spitzenverband, 2021).

9. Conclusion and Policy Implications

This evaluation does not stop at a mere description of "which city possesses the most digital health" but proceeds to a more critical examination of "which city has the best management of digital health resources." The outcomes reveal that the effectiveness of the digital health system in Germany is not necessarily linked to the magnitude of the city’s economy or the number of tech firms in the area. On the contrary, it is a key indicator of the existence of strategic cooperation, a concern for fairness, and an academically strong, wholly owned teaching hospital.

On comparing the convergence dynamics of inflation targeting with theoretical results from the literature, substantial insights can be derived.

1. **For High-Performing Regions (Rhineland-Pfalz, Aachen, Dresden):** Sustainability and scaling are the challenges. The model of Rhineland-Pfalz, applied state-wide, should be examined and modified by other states. The profound digital transformation of university hospitals, such as Aachen and Dresden, should be used as the foundation for wider regional health information exchanges and for the establishment of communication with smaller hospitals and private practices in the area.

2. **For Major Metropolises (Munich, Frankfurt, Stuttgart):** Overcoming fragmentation should be the chief aim. Health insurers, city and state governments, together should assume more active roles as conveners and coordinators. The objective should be to establish urban digital health platforms that are well interconnected and inter-service provision between rival entities, that is, transitioning from a bunch of efficient silos to an efficient system.

3. **For National Policymakers:** The continuous divergence between CCR and BCC efficiency emphasizes the necessity of a more unified national digital health strategy. The Digital Healthcare Act (Digitale-Versorgung-Gesetz - DVG) was an advancement, but a more holistic approach is required to facilitate all areas getting to the constant returns to scale. This entails financial support not only for technology but also for the infrastructure that will manage the coordination needed to connect different initiatives.

To sum up, the use of DEA and TOPSIS has yielded a strong and quantitative confirmation of the trends seen in the German digital health literature. It validates the effectiveness of the models based on public health and coordination and exposes the unrecognized inefficiencies in the richest and least integrated urban healthcare markets of Germany. Germany's future does not just depend on the additional investment in technology, but more on the wise investment in the governance, coordination, and fair distribution of that technology. The most efficient cities of today serve as the model for the rest of the country to follow.

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