ISSN 2475-529X

Research Article

Journal of Nursing & Healthcare

Performance in Covid-19 Vaccination in The First Half Year: A Review and Analysis of Decentralized and Centralized Vaccination Organizations

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Submitted: 03 Mar 2023; **Accepted**: 09 Mar 2023; **Published**: 25 Mar 2023

Citation: *Alscher, A., (2023). Performance in Covid-19 Vaccination in The First Half Year: A Review and Analysis of Decentralized and Centralized Vaccination Organizations, J Nur Healthcare. 8(2), 145-157.*

Abstract

Western industrialized countries had similar vaccination policies in the COVID-19 pandemic but different vaccination organizations. Analyzing their performance in terms of publicly available vaccination rates revealed that decentralized as in the United States and centralized systems as in the United Kingdom had comparable start peak performance on international level and showed no significant differences in performance on a subnational level in Germany. In comparing peak performance, a mixture of both systems showed a 0.95% higher protection rate which would have resulted in estimated 17'995 less infections, 251 less Covid-19 related death and US$ 4.3 million less hospitalization costs in the United States. A mixture of centralized vaccination organization such as vaccination centers and decentralized vaccination through regional doctor practices deliver best results in the first phase of pandemic outbreaks given the first half year experience in the COVID-19 pandemic.

Keywords: COVID-19 (Pandemic), Vaccination, Vaccination delivery, Health policy, Organizational structure

Introduction

Pandemics have been the most dangerous and life-threatening circumstances for humankind (e.g., Black Death caused 50-60% of death of the European population in the 14th century, Trisal et al., 2020) [1]. The management and processes for handling crises seem to be eventually one of the biggest challenges for humankind. Vaccination has been perceived as key and most economical and effective approach to fighting the COVID-19 pandemic since its declaration [2, 3]. How to setup the vaccination strategy is a general economic problem since resources for mass vaccination are constrained, i.e., not only the supply of vaccines but moreover also the medical facilities and healthcare workers capacity. Policy makers must select and decide an optimal allocation strategy under these constraints to maximize the overall effect of mass vaccination (Kitagawa and Wang, 2021). "Yet, the endgame of the pandemic is not vaccines; it is vaccination" and application of resource optimization of policy makers [4, 5]. Dai & Song (2021) explicitly ask for research to understanding of best management practices such as prioritization policies, distribution strategy, appointment scheduling, and demand management [4].

There is still a missing analysis how the countries really delivered vaccination and how their relative performance unfolded. Though some countries achieved already over 90% full vaccination rates such as United Arabian Emirates (99%), Brunei (94%), Malta (93%), as well as Chile, Qatar, and Portugal (each 92%)[i], these smaller countries may not be compared to the larger industrialized countries and their endeavors to manage the pandemic crisis such as compared with the largest western, industrialized countries by GDP [6] United States [US], Germany, United Kingdom [UK], France, Italy, Spain, Netherlands, Switzerland, Poland, Sweden (see Table 1).

[i] *Cf. https://www.nytimes.com/interactive/2021/world/covid-vaccinations-tracker.html, recorded 04/28/2022.*

Table 1: Selection of United States and largest European countries based on GDP in billion [bn] (IMF, 2022)[ii]

Country	2017	2018	2019	2020	2021
United States [US]	$ 19.480	$ 20.527	$ 21.373	$ 20.894	$ 22.996
Germany	$ 3.665	$ 3.951	$ 3.863	$ 3.781	$ 4.230
United Kingdom [UK]	$ 2.640	$ 2.829	$ 2.744	$ 2.638	$ 3.108
France	$ 2.592	$ 2.780	$ 2.707	$ 2.551	$ 2.940
Italy	$ 1.951	$ 2.076	$ 2.001	$ 1.848	$ 2.120
Spain	$ 1.317	$ 1.428	$ 1.398	$ 1.247	$ 1.440
Netherlands	$ 834	$ 915	$ 902	$ 886	$ 1.008
Switzerland	$ 680	$ 706	$ 715	$ 708	$ 811
Poland	$ 527	$ 586	$ 566	$ 581	$ 655
Sweden	$ 541	$ 556	$ 529	$ 529	$ 622
YoY Change (average)		*6,2%*	*1,2%*	*-3,1%*	*12,0%*

In general, a faster vaccination leads to a faster economic recovery. Thus, the performance of vaccination, i.e., how fast it is delivered, is quite important as it brought the countries out of lockdown and business constrainment settings so that the overall economy could rise to and even over its former size and scope (see Table 1 last line with year over year [YoY] change rates). This study focuses on the first phase of the vaccination implementation which refers to the vaccination of the 'fraction of willing' accounting for 50-70% of the population for COVID-19 vaccines in most industrialized countries whereas the second phase of the vaccination addresses the vaccine hesitant group [7, 8]. Most countries reached 50% of full vaccination in July 2021, i.e., approx. half a year after vaccination start so that this study focus on the the first half year of 2021. Though those countries had similar vaccination policies in the COVID-19 pandemic, e.g., using at least one of the four Western vaccination manufacturer Johnson&Johnson, Moderna, Oxford/AstraZeneca or Pfizer/BioNTech, approving them in December 2020, setting up national vaccination policies, there had been a striking difference in the vaccination organizations between centralized and decentralized vaccination systems. On the poles of the organizational axis had been US and UK. UK managed a centralized vaccination process steered through the body of the National Health Service [NHS] where US operated in their decentralized healthcare system through thousand of independent vaccination providers [4]. This means that also the infrastructure to apply, book, or register for a vaccine was different from a singular source in centralized systems to numerous online portals of different providers in the decentralized system. Though literature argues for a centralized system with a "push" model registration, wait list, and notification features , there has been no larger empricial study for testing the hypothesis. Thus, this study follows an inductive empricial approach with the research question [4, 9].

RQ: Did centralized or decentralized vaccination organization systems perform better in the first phase of the vaccination process?

The paper starts with a literature review (part 2) on articles related to "COVID-19" AND "vaccination" in public health journals. The articles are clustered into (i) measures parallel to vaccination, (ii) behavior and information before vaccination, and (iii) ways of offering vaccination which become most relevant for this research study. The Methods & Data section (part 3) explains the performance variable as the total vaccination rate per time period per 100 inhabitants and refers to the data sources of the international and national data sources. In the Result section (part 4), three different organizational systems of centralized, decentralized, and mixed systems are outlined and a performance analysis on country level is performed. The second subnational analysis focuses on the country with the highest monthly vaccination rate, i.e., Germany, and reveals that there is no significant performance difference in centralized vs decentralized systems as well as in small vs big federal states. In the Discussion section (part 5), the paper advises policy makers to invest time and effort to design mixed vaccination process such as in Germany and use both approaches to maximize performance. Finally, the paper concludes (part 6) with the limitation of the research, direction for research for the time after the first six months, and the core finding for policy makers to implement digital platforms as a key element in fighting next pandemic outbreaks.

Literature Review

The scientific database Ex Libris Primo showed 43'149 results of articles in peer reviewed journals with the search string "COVID-19" AND "vaccination" (both in any fields). If restricted to a search in the title field, the database still presented 5'037 articles (as of 2022/05/04). The search was limited to health related quality business and management journals to sort out other

[ii] *Russia [#5] and Turkey [#8] were removed in the list of the largest European countries due to another political regime and different vaccination products with Sputnik and Sinovac The selected 10 countries represent also the largest 10 countries in the OECD report 2021 (OECD, 2022) with a GDP over $ 500bn without countries from other continents.*

[iii] *Spain 58%, United Kingdom 57%, Netherlands 54%, Italy 52%, Germany 52%, United States 52%, Switzerland 51%, and France 50%, except Poland 46% and Sweden 40%, cf. data of 07/31/2022 in Ourworldindata (2022).*

medical or corporate disciplines related studies and included 35 scientific (peer reviewed) articles were found with the very wide search string "COVID-19" AND "vaccination" (in any field). The articles were divided into three areas of (i) measures parallel to vaccination (17 articles), (ii) behavior and information before vaccination (10 articles), and (iii) ways of offering vaccination (8 articles).

(i) In the first field of (i) measures in *parallel to vaccination* (for a tabular overview, see Appendix 1), the healthcare management articles emphasize the use of nonpharmaceutical interventions (NPI) above all mask usage and social distancing (Lee et al., 2021; Mingolla & Lu, 2022; Rao et al., 2021) and that their revoking would result in additional infections, hospitalizations, and death [10]. For hospitalization, there is a clear vote for prefering COVID-19 prognosis and elderly people [11]. On the other side, it is shown that lockdown measures led to higher mental health issues (especially in lower socioeconomic positions) [12, 13]. For increasing health care efficiency, larger scale primary care organizations with telemedicine offering are suggested [14] and even willingness to pay were shown to have increased significantly during COVID-19 [15]. To mitigate the negative effects, pandemic unemployment compensation helped to sustain health care spending of lower socioeconomic positions and service, retail, and industrial sectors need to be supported [16, 17]. For modeling the pandemic, agent based simulation beats dynamic system modelling [18]. Testing willingness was positively related to convenience, social capital, socioeconomic status, and religiosity and testing localization can be facilitated through simple sampling algorithm [19, 20]. Overall it is shown that countries with greater population density, higher income, more democratic political systems were faster in fighting pandemic and that populations with higher confidence in the governmental management more easily accepted restrictions [21, 22]. Overall excess deaths in eight larger European countries were estimated at 18,614 with premature mortality costs of €2.89 billion [23].

(ii) In the second branch of behavior and information *before vaccination* (for a tabular over view, see Appendix 2), it is shown that vaccination willingness in Europe is around 74% while the largest concern around vaccination referred to side effects and strong religious beliefs were related with higher vaccination hesitancy [24, 25]. For motivating vaccination willingness, cost and duration of immunity are significant as well as areas of low wasterecycling and employment rate [26, 27]. Community advisory boards may help under conditions of accessible and available services, culturally competent programming, trusted community, faith leaders, and social safety nets [28]. However, vaccine information reduces peoples' willingness to adhere to nonpharmaceutical interventions (NPI, see research area (i) above) despite the finding that higher levels of general COVID-19 related knowledge, especially from interpersonal communication and social media, increased engagement in protective behavior [29, 30]. Leveraging novel methods of communication and dissemination (in social media and with partnerships) seems to be a fast measure to close the gap in care delivery of vaccinations [31]. In terms of financial implications, 100% effective vaccination is estimated to be worth 11'400€ while effectiveness below 50% shows no value, budget is said to be more economic than pricing vaccines while demanding at leat 90% vaccine efficacy, and majority of industrialized countries used performing payment schemes for primary care physicians [32-34].

(iii) Regarding the ways of *offering vaccination* (for a tabular overview, see Appendix 3), Dai (2021) calls out for the three research streams of a) supply, b) demand, and c) matching supply with demand:

a) For supply, Kim & Lee (2022) show that extending the interval between first and second doses of vaccines developed in Europe and the US increase effects of vaccination (not in China) but NPI (see research area (i) above) remain important [2]. Allocating resources proportional to population seems to be also suboptimal and increases infections and deaths, resulting in a high cost of fairness [35] as opposed to the more effective approach of scheduling vaccination according to individual cumulative risk [36].

b) For demand, NonHispanic White and Asian patients were more likely to receive the vaccine, whereas Hispanic, Black, and American Indian/Alaskan Native/Pacific Islander were less likely to receive the vaccine [37].

c) For matching supply with demand, people seem to prioritize either virus spreaders and essential workers or those who were most at risk because of a preexisting health condition while "first come first served", highest willingness to pay or "lottery" approaches were not preferred [38]. However, there had been evidence from Ohio that conditional cash lotteries for vaccination incentive scheme increased vaccination by 1.5% and prevented at least one infection for every six vaccinations [39]. From a financial perspective, operating costs decrease with the size of the vaccination unit due to economies of scale in larger vaccination operations from 41% in GP practices to 8% in small centers, 4% in medium-sized, and 2% in large centers [40].

In this research overview, we are still missing answers to our questions how the countries performed in the vaccination organization, and which were the best approaches in performing in the first phase of vaccination in the COVID-19 pandemic settings.

[iv] *Ex Libris Primo covers hundreds of millions of articles, see https://gm.primo.wrlc.org.*

[v] *The US ABS (Association of Business Schools) Academic Journal Guide 2021 lists three journals with a high rating of "3": Health Economics, Journal of Health Economics, and Health Services Research. The German VHB ranking 2022 adds two further A-ranked journals with Health Care Management Science and Medical Decision Making. The ABDC (Australian Business Deans Council) Journal Guide 2019 complements the two journals European Journal of Health Economics and Health Policy as "A" rated to our selection.*

[vi] *Three articles were disregarded since the topic was on another vaccination than Covid-19.*

Methods & Data

The performance of the vaccination management is operationalized as the relative number of total vaccinations. This main outcome variable is calculated by the number of vaccinations per area (country or state) per time period (month or day) divided by the total population times 100.

Vaccination Rate (VaccR) = total vaccinations per time period / population * 100

The number of vaccinated people is deemed to be protected from the disease to a high percentage (depending on the efficacy of the vaccine) and prevents other people from getting infected and spreading further Corona viruses [18]. Since every positive COVID-19 case can lead to further infections, increases the (health) costs for society, blocks hospital capacities, and leads to further health complications, the cumulative number of total vaccinations is an appropriate measure to prevent further spread of the virus. Supported by research the total number of first vaccination is much more important than the total number of full vaccinations in US and Europe. According to Kim & Lee (2022, p. 3) this is based on three assumptions: "1. the first dose provides good enough protection (the first dose's efficacy is higher than the marginal efficacy gains from the second dose); 2. protection after the first dose does not wane too quickly; 3. delaying the second dose does not lower the efficacy of full vaccination." The authors illustrated the impact in a simple thought experiment that in a time frame of 12-16 weeks for inoculating 70% of the population with a 90% first dose vaccine efficacy and a 95% second dose vaccine efficacy, the results would be: (1) a 63% protection in the first scenario of giving out only first doses versus (2) a 35% protection level of the population in the second scenario of distributing first and second doses equally. Given the empirical support for scenario (1) in Western industrialized countries (i.e., prioritizing first dose delivery) the number of total vaccination is much more important than the number of full vaccination in the first wave of the vaccination efforts. It is arguable that only the number of first doses may count but, since the paper aims to analyze the overall performance of vaccination, the number of total vaccinations including first and second doses is considered.

The health data of the United States and the nine European countries (Germany, United Kingdom, France, Italy, Spain, the Netherlands, Sweden, Poland, and Switzerland) was accessed by the database https://ourworldindata.org/(Ourworldindata, 2022) [41]. For the German federal data, the official data from the German government was provided by the Robert Koch Institute (RKI, 2022) [42]. The data was recorded, analyzed, visualized with statistic programs R-4.2.0, R Studio 2022.02.2, and Microsoft Excel. In addition, 14 interviews with representatives from health authorities and research facilities in USA, UK, and Germany were conducted from January to April 2022 to validate the findings.

Results

Country analysis of vaccination in Western, industrialized countries

Important for the selection and comparison of the ten countries was the usage of the same vaccination types. All ten countries used at least three of the four Western vaccination manufactures: Johnson&Johnson [J], Moderna [M], Oxford/AstraZeneca [O], Pfizer/BioNTech [P] (see following Table 2).

Table 2: Usage of vaccination types across countries

Country	JMOP	JMP	MOP	MP	OP	Total
United States [US]		97%		3%		100%
Germany	100%					100%
United Kingdom [UK]			93%		7%	100%
France	97%		3%			100%
Italy	100%					100%
Spain	96%		4%			100%
Netherlands	97%		3%			100%
Switzerland		100%				100%
Poland	96%		3%			100%
Sweden			100%			100%

Abbrev.: Johnson&Johnson [J], Moderna [M], Oxford/AstraZeneca [O], Pfizer/BioNTech [P]

[vii] *The database sourced the data from the ten government databases: https://data.cdc.gov/Vaccinations/, https://impfdashboard.de/, https://coronavirus.data.gov.uk/details/vaccinations, https://www.data.gouv.fr, https://raw.githubusercontent.com/italia, https://github.com/mzelst/covid-19, https://www.gov.pl/web/szczepimysie/, https://www.mscbs.gob.es/profesionales/saludPublica/, https://fohm.se/smittskydd-beredskap/utbrott/, https://opendata.swiss/en/dataset/covid-19-schweiz.*

[viii] *The Robert Koch Institute (RKI) is a German federal government agency and research institute responsible for disease control and prevention (https://www.rki.de/).*

Most of the countries (Germany, France, Italy, Spain, Netherlands, Poland) used vaccination doses of all four manufacturers whereas United States and Switzerland waived British Oxford/AstraZeneca and UK and Sweden disregarded US Johnson&Johnson vaccines. Hence, Moderna [M] and Pfizer/BioNTech [P] were used in all ten countries.

The number of total vaccinations shows two patterns across the ten countries in the first vaccination phase of the first half year 2021 (see Table 3).

Table 3: Ranking based on cumulative number of total vaccinations divided by population size per 100 inhabitants

January 21			February 21			March 21			April 21			May 21			June 21		
Rank	Country	VaccR	Rank	Country	VaccR	Rank	Country	VaccR	Rank	Country	VaccR	Rank	Country	VaccR	Rank	Country	VaccR
1	UK	15	1	UK	31	1	UK	53	1	US	US	1	UK	97	1	UK	116
2	US	11	2	US	27	2	US	52	2	UK	UK	2	US	95	2	US	103
3	Switzer-land	4	3	Switzer-land	9	3	Switzer-land	18	3	Germany	Germa-ny	3	Germany	61	3	Germany	90
4	Spain	3	4	Poland	9	4	France	18	4	Spain	Spain	4	Italy	59	4	Spain	90
5	Italy	3	5	Sweden	9	5	Italy	17	5	France	France	5	Spain	58	5	Nether-lands	89
6	Sweden	3	6	Spain	8	6	Spain	17	6	Italy	Italy	6	Switzer-land	58	6	Switzer-land	87
7	Poland	3	7	Nether-lands	8	7	Germany	17	7	Switzer-land	Switzer-land	7	France	57	7	Italy	86
8	Germany	3	8	Germany	8	8	Poland	17	8	Sweden	Sweden	8	Nether-lands	56	8	France	85
9	France	3	9	Italy	7	9	Sweden	16	9	Poland	Poland	9	Sweden	54	9	Sweden	80
10	Nether-lands	2	10	France	7	10	Nether-lands	14	10	Nether-lands	Nether-lands	10	Poland	53	10	Poland	77

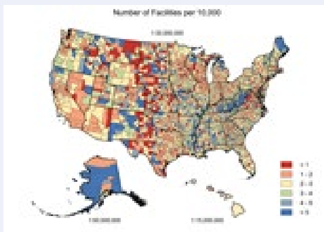
The first pattern is the fast vaccination execution of UK and US. This phenomeon has been also described in literature as "UK's vaccination programme [as] a front runner globally… United Kingdom has administered more covid-19 vaccine first doses per 100 people (19%) than any other nation" [43]. In general, UK and US had a start advantage of approx. two weeks with a faster vaccine approval as the first person was vaccined in UK (Margaret Keenan) on December 8th, 2020, and in US (Sandra Lindsay) on December 14th, 2020. In the European Union [EU], the European Medication Agency approved the first COVID-19 vaccination on December 21st, 2020, and the start of vaccination in all EU countries startet on December 26th, 2022. However, the starting advantage is not the sole explaining factor for the vaccination speed in UK and US since both countries continued to stay ahead with a larger difference of 20-40 doses more per 100 inhabitants until April.

The second pattern represents the catchup of the European Union countries from April until July. Above all Germany, which had a weak start and ranked #7 and #8 in the first three months, speeded up for the missed difference, outperformed the other countries, and followuped with UK and US. For this reason, the top three countries are further analyzed in the following section.

Different vaccination organizations in US, UK, and Germany

The US and UK had quite the opposite organizational approach of handling vaccination management: The US followed a "decentralized" vaccination approach whereas UK with their National Health Service [NHS] managed a "centralized vaccination process" [4]. In addition to the black and white of centralized and decentralized systems, Germany implemented a mix of decentralized centralized vaccination organization. In the general pandemic management in Germany starting early 2020, subnational and local authorities became the key actors of crisis management in the beginning and afterwards, centralized government regulation gained in importance with functional orientation and increased vertical coordination [44]. The vaccination management was reverse. The German government and health ministry passed the *National Vaccination Strategy* in October 2020 about risk groups and vaccination orders [45], and the execution and implementation of vaccination centers had been delegated to the 16 federal states and from there also partially to local authorities in larger federal states (see Figure 1 for an overview).

Figure 1: Three types of vaccination organization approaches [46-48].

Vaccination	US	Germany	UK
Approach	Decentralized	Mixed (Centralized decentralized)	Centralized
Provider	US government with hospitals, doctors, pharmacies, supermarkets, community vaccination sites	German government with federal state governments (from April 2021 also GP doctors)	NHS (National Health Service)
Vaccin. sites	> 70’000	474(+ 65’000 doctors since 04/2021)	2’057
Distribution	(UPMC, 2020) 	(Neumeier, Stefan, 2022, p. 44) 	(NHS, 2020) 
Prioritization	*First healthcare workers, then age*	*Age & care residents & healthcare workers, then special groups*	*First care residents, then age and health care workers*
Willingness	67% (Malik et al., 2020)	*75%* *(BMG 2021)*	74% (Sherman et al., 2022)

In the decentralized US vaccination organization, the US government managed the order of the vaccines and then allocated and contracted over 70’000 hospitals, doctors, pharmacies, supermarkets, and community vaccination sites for the vaccination process [49]. The German government delegated the ramp up of the vaccination centers to federal state governments which did it on their own or delegated further to local authorities. In total, 474 vaccination centers had been established in Germany [50]. From mid April 2021, the German government also allocated vaccine doses to 65.000 GP and specialty doctors [47]. In the centralized UK system, the National Health Service [NHS] organized the vaccination process on 2’057 sites with 1’597 pharmacies, 1’079 GP, 128 vaccination centers, and 240 hospital hubs [51]. The willingness to participate in the vaccination process was around 70% in all three countries.

In terms of vaccination performance, we diagnosed the fast speed of UK in the beginning, followed by the catch up of US, and the endrallye of Germany in the first half year of the vaccination process (see following Table 4).

Table 4: Total Vaccinations per 100 inhabitants per month in US, Germany, UK (Ourworldindata, 2022)

Country	January	February	March	April	May	June	Max	Min
US	9.7	15.2	25.5	27.5	15.3	7.7	27.5	7.7
Germany	2.8	4.5	9.4	18.6	25.2	29.6	29.6	2.8
UK	14.6	16.8	21.7	20.3	23.6	18.9	23.6	14.6

The data reveals that Germany reached “peak performance” in vaccination management in June 2021 with almost 30% of the population with one dose in one month. For this reason, we want to drill a level deeper in the vaccination process of the federal states in Germany to understand how Germany achieved this performance.

State analysis of vaccination organization in Germany

Germany with its 16 federal states had 16 different approaches in the vaccination organization with 474 vaccination centers respectively 0.31 million inhabitants per vaccination center. This means that the people had at least 16 different providers with at least 16 different vaccination portals for booking or registration (see following Table 4 for an overview).

Table 5: Provider of vaccination booking/registration in Germany accross federal states

RKI-ID	Federal State	Inhabitants (in mn)	Area (sqm)	# Vacc. centers	Inhabitants (mn)/center	Catchment (Neumeier 2022)	Vaccination approach	Provider for vaccination booking	Link for booking/registration
1	Schleswig-Holstein	2,9	15.801	28	0,10	federal	**centralized**	CTS Eventim	https://ticket.impfen-sh.de/sh/start/termine
2	Hamburg	1,9	755	1	1,85	federal	**centralized**	Authority/ KBV	https://www.hamburg.de/corona-impfstationen/
3	Lower Saxony	8,0	47.710	50	0,16	county	**centralized**	Majorel (Arvato)	https://www.impfportal-niedersachsen.de/portal/#/appointment/public
4	Bremen	0,7	419	3	0,23	federal	**centralized**	Digital Guest Sol. GmbH	https://impfzentrum.bremen.de/
5	North Rhine-Westphalia	17,9	34.112	53	0,34	county	decentralized	*several*	https://termin.corona-impfung.nrw
6	Hessen	6,3	21.116	28	0,22	county	decentralized	*several*	https://impfterminservice.hessen.de
7	Rhineland-Palat.	4,1	19.858	32	0,13	county	decentralized	Authority	https://impftermin.rlp.de/de/
8	Baden-Württemberg	11,1	35.748	53	0,21	federal	decentralized	*several*	https://www.dranbleiben-bw.de/#impfangebote
9	Bavaria	13,1	70.542	125	0,11	county	decentralized	Accenture/BayIMCO	https://impfzentren.bayern/
10	Saarland	1,0	2.571	4	0,25	federal	**centralized**	Samedi	https://www.impfen-saarland.de/
11	Berlin	3,7	891	6	0,61	federal	**centralized**	Doctolib	https://www.doctolib.de/institut/berlin/ciz-berlin-berlin
12	Brandenburg	2,5	29.654	14	0,18	federal	decentralized	Authority	https://brandenburg-impft.de/corona/de/corona-schutzimpfung/#
13	Mecklenburg-WP	1,6	23.295	16	0,10	county	decentralized	Authority	https://www.corona-impftermin-mv.de/
14	Saxony	4,1	18.450	15	0,27	federal	**centralized**	T-Systems	https://sachsen.impfterminvergabe.de/
15	Saxony-Anhalt	2,2	20.457	14	0,16	federal	decentralized	*several*	https://coronavirus.sachsen-anhalt.de/hotlines/
16	Thuringia	2,1	16.202	32	0,07	federal	**centralized**	KVT Notdienst gGmbH	https://www.impfen-thueringen.de/terminvergabe/index.php
	TOTAL	83,2	357.581	474	0,31	mixed	mixed		

In the analysis of the distribution of the vaccination centers, Neumeier (2022) classified the catchment area for the single vaccination centers [50]. However, this does not fit in all cases with the centralized and decentralized organization of how the federal state took control of the vaccination appointment slots. In most federal states where *federal catchment* was found, a *centralized* system with a central vaccination platform was used such as in the seven federal states SchleswigHolstein (CTS Eventim), Hamburg (authority), Bremen (Digital Guest Solution GmbH), Saarland (samedi GmbH), Berlin (Doctolib GmbH), Saxony (T-Systems), and Thuringia (KVT Notdienst gGmbH). And in most states where *county catchment* was given, a *decentralize*d system was implemented as in the five federal states of North RhineWestphalia, Hessen, RhinelandPalatinate, Bavaria, Mecklenburg West Pomerania. However, there had been deviations. In Lower Saxony, county catchment was found but there had been a centralized booking platform provided by Majorel (Arvato Systems, a Bertelsmann subsidiary). On the opposite, there had been also federal catchment with decentralized multiple vaccination offerings such as in Baden-Württemberg, SaxonyAnhalt, and Brandenburg. Following the research question which vaccination organization performed best in the first phase, we analyzed the two hypotheses whether centralized or decentralized systems outperformed (i.e., 8 decentralized vs 8 centralized, see table above) and whether there was a small vs big population effect in the data (i.e., 7 large vs 9 smaller federal states with less than 4mn inhabitants), see following tables over the period 01/01/2021 until 06/30/2021 (n=181 days).

Table 6: Daily vaccination rate per 100 inhabitants in categorized German federal states

States	Mean (μ)	Stand.Dev.	States	Mean (μ)	Stand.Dev.
Centralized	0.4912	0.4168	**Large**	0.4978	0.4237
Dezentralized	0.4988	0.4283	**Small**	0.5394	0.4723
t-Stat. $H_0(\mu_C=\mu_D)$	*0.02*		t-Stat. $H_0(\mu_C=\mu_D)$	*0.10*	

In a simple mean comparison hypothesis testing, no significant differences were found between centralized vs decentralized organizations. Both organizations had a mean of 0.5 daily vaccinations per 100, i.e., 15 vaccination per month (30 days), with a nonsignificant difference of the means (t-statistic of 0.02). The same holds for the difference between small vs large federal states with a mean of approx. 0.5 daily vaccinations per 100 and a nonsignificant difference of the means (t-statistic of 0.10).

Discussion

Implications for economy and society

The vaccination organization is exposed to various internal factors such as setup, running, and managing the staff which is subject to the national or federal management. External political and socioeconomic influences as well as distribution of the vaccines also played a role. In terms of vaccination organization, the US followed a "decentralized healthcare system [which] means almost everyone… has to actively seek vaccination" whereas UK with their National Health Service [NHS] managed a "centralized vaccination process and residents are notified by the NHS when it's their turn to get vaccinated" (Dai & Song, 2021, p. 458). Decentralized "pull model" systems, where the people have to actively book vaccine appointments, seems inefficient and inequitable when vaccine demand is far higher than supply [4]. In contrast, centralized "push model" systems seem to be the better approach where citizens enter a registration portal including a centrally managed waitlist and notifications as implemented also by the fast vaccinating country Israel [9]. However, as shown in the data (see Tables 3 and 4) this does not hold for good since the decentralized organization of the US even overtook the centralized organization of UK in April based on the number of total vaccinations. In addition, the quasi experimental setup of centralized and decentralized organizational settings in the state of analysis of Germany revealed no significant overperformance for any setup given that the relative vaccination dosis distribution had been overall the same in Germany. Moreover, Germany

[ix] *I.e., mean protection rate = (additional vaccinated at the end + additional vaccinated at start) / 2 * vaccination efficacy rate = (0 + 2.1) / 2 * 90%) = 3.98%.*

reached overall peak performance in vaccination rate (see Table 4) because the added decentralized vaccination delivery overy 65'000 doctors/GPs over all federal states. Comparing the peak performance of a monthly vaccination rate (VaccR) of 29.6 in Germany vs 27.5 in the US, this yields an overperformance of 2.1. This 2.1 additional vaccination rate implies an average protection rate of 0.95% over a month. This number is similar to the 1.5% increase in vaccination through the implementation of conditional cash lotteries (CCLs) as used for Ohios vaccination incentive scheme [39] or 8% COVID-19 case reduction over 6 months basedon spatial allocation process according to stores, restaurants, retail, healthcare, education, or other facility locations [5]. The additional protection rate of 0.95% would have led to 17'955 less infections given the 1.89mn new infections in US in April 2021 [41]. Based on the COVID-19 infection hospitalization ratio [IHR] of 2.1% [50], the hospitalization number of the possibly protected but now infected was 377 people representing costs of US$ 4.3 million (Ohsfeldt et al., 2021; based on overall median hospital costs US$ 11'267 per COVID-19 patient over 6 days) [53]. Given the overall symptomatic case fatality risk (the probability of dying after developing symptoms) of COVID-19 of 1.4% (substantially lower than initially confirmed case fatality risk of4.5%) [54], this represents 251 less COVID-19 related death in US over one month. Compared to the 18'614 excess death in eight larger European countries in the first 5 months of the Corona outbreak [23] which implies an average of 465 excess death per country per month or the 106 fewer death over 6 month in Missouri [5], this number of 251 does not seem to be that small given just the organization setup. However, in the literature review we found other social factors for compliance against infection spreading such as confidence in governmental management [22], income loss from COVID-19 [55] and vaccine hesitancy factors such as religiosity or belonging to a ethnical minority [37] also affect the protection level and complicates our statement of implications.

Implications for pandemic management and policy makers

Though Dai (2021) contends the superiority of the centralized "vaccination push" model compared to the decentralized "pull" model of vaccination, we have seen that the UK centralized and the US decentralized system both had their advantages and that there was no significant difference between centralized and decentralized systems in the mixed organization in Germany [4]. Policy makers should invest time and effort to use both benefits of centralized and decentralized approaches. In the literature review, Garratini et al. (2020) called for larger scale vaccination care organization based on economic theory and in particular [14], Schulenburg (2021) showed the reduction of operating costs from 41% in GP practices to 2% in large centers [40]. Apart from measures and behavior in parallel to vaccination (as shown in the literature review of Appendix 1) especially nonpharmaceutical interventions (NPI) above all mask usage and social distancing [56-58], the design and choice of the organization structure of vaccine delivery can have a significant impact as shown in the study. Policy makers and pandemic managers for vaccination may start fast with large and cost effective vaccination centers (see UK peak performance in the beginning in Table 3 and 4) but also plan and implement the roll out to the overarching existing health infrastructure of doctors/GP and pharmacies as shown in the US and Germany cases. Combining both systems seems to be a best practice for the first phase of the vaccination process for the next pandemic. For the COVID-19 pandemic which has now gone over the first phase, the challenge in the following phases seems to be more to target the vaccine hesitant group by leveraging novel methods of communication and dissemination through social media and partnerships [31], through special offers such as conditional cash lotteries [39], addressing special locations and facilities [5] or combining it with influenza vaccinations [59].

Conclusion

Limitations and direction for future research

This study focused on two analyses, the country wide examination of ten selected largest Western industrialized countries and the 16 German federal states so that it was a conscious limitation of examining peak performance in COVID-19 vaccination. First, it would be interesting to compare the results with other political vaccination regimes such as in Asia oder Middle East. Second, future research may also analyse the differences in the seven regions or 250 primary care trusts in the NHS of UK and in the 50 federal states of the US. In Germany, the federal state Saarland stood out and ranked 71 days as the #1 with the highest daily vaccination over the first half year. Hence, an indepth-analysis of the underyling drivers, patterns, and adoption characteristics of the inhabitants would be a promising study given the high vaccination rate. On the opposite side, other federal states with exceptionally low vaccination rates could be also an interesting field for researching vaccine hesitancy. Finally, this study was limited to the first phase, i.e., the first half year of the vaccination. Other dynamics and other challenges in the subsequent development of the pandemic and vaccination organization offer another wide range of research which might also challenge the findings of this study [60].

Summary

Despite some articles in the literature emphasizing the central organization for vaccination as the best one (such as shown in UK), the first analysis showed that centralized organization had a start advantage but also decentralized organized vaccination (as used by US) showed a superior performance with even higher monthly vaccination rate. In addition, Germany which implemented a mixed approach of centralized and decentralized system delivered even the monthly peak performance of vaccination rate compared to the other countries. By following the inductive research question, which vaccination organization system performed best in the first phase, Germany was selected as an experimental playground to analyse and understand the performance differences between centralized and decentralized vaccination approaches. Finally, there was no significant evidence for overperformance of centralized or decentralized organizations, but a mixed or staggered approach seemed to be best. To conclude, this study gives strong evidence for policy makers to consider respectively mix both approaches as Germany did with centralized vaccination centers and decentralized doctor/GP vaccination approaches in the first phase of vaccination.

I. Appendices

1. Literature review part 1 - Measures and behavior in parallel to vaccination

Authors	Method	Findings/Results
Ceylan et al., 2020	Literature review	Most urgent socioeconomic measures to combat the negative disease effects related to unemployment with its income effects and security of all sectors. To prevent unemployment, service, retail & industrial sectors need to be supported.
Chhatwal et al., 2021	Simulation model	Lifting of NPIs would result in additional deaths, infections, and hospitalizations. Sensitivity analysis showed that with the vaccine efficacy of 70%, the difference in outcome
Evangelist et al., 2022	Regression (insurance and credit data)	Federal Pandemic Unemployment Compensation (FPUC) payments on bolstered health care spending during the Covid pandemic, but that both the negative consequences of unemployment and moderating effects of federal income supports were greatest in states that did not adopt Medicaid expansion. Emergency federal spending helped to sustain health care spending during a period of rising unemployment.
Garattini, Badinella Martini, et al., 2020	Theoretical	Call for largerscale primary care (PC) organizations with planning and budgeting from business administration principles and increased efficiency through telemedicine (TM) instead of pricing and competing as in economic theory.
Gonsalves et al., 2021	Simulation model	A simple Thompson sampling algorithm allow policymakers to target SARS-CoV-2 testing locations
Hanly et al., 2021	Regression	Estimated excess deaths in 8 European countries were 18,614 (77% in men) and lost years were 134,190 with premature mortality costs of €2.89 billion (highest in Spain, Italy, and Netherlands).
Himmler et al., 2021	Experiment	Willingness to pay (WTP) for an outbreak warning system increased significantly (by 50%) during actual pandemic (COVID-19) to €20-30 per month.
Lee et al., 2021	Simulation model	At least 75% face mask use to relax social distancing and school closure measures while keeping infections low
Mingolla & Lu, 2022	Simulation model	Stay at home requirement is the most effective measure in reducing ICU hospitalizations in regions encountering the outbreak early, its effectiveness decreases in regions encountering the outbreak later
Rao et al., 2021	Simulation model	Only 100% coverage of masks reduce the effective reproductive number with no social distancing
Serrano-Alarcón et al., 2022	Simulation model	Easing lockdown measures rapidly improves mental health, in lower socioeconomic positions (education or financial). Overall, mental health appears to be more sensitive to the imposition of containment policies than to the evolution of the pandemic itself.
Sicsic et al., 2022	Survey experiment	Individuals who felt at greater risk from COVID-19 or expressing high confidence in the governmental management more easily accepted restrictions. Policies close to a targeted lockdown or with medically prescribed self-isolation most satisfying for population and achieving high gain in average welfare.
Stillman & Tonin, 2022	Regression	Convenience, social capital, socioeconomic status, and religiosity were positively related to testing willingness.
Street et al., 2021	Experiment	Hospitalization preference for COVID-19 prognosis and for those 65 years and older.

Summan & Nandi, 2021	Regression and Simulation model	Countries with larger populations and better health preparedness measures had greater delays in implementation. Countries with greater population density, higher income, more democratic political systems were faster. National school closures did not significantly change mobility.
Wang & Flessa, 2020	Modeling	SIR model (susceptible, infectious, recovered) cannot properly analyse first weeks due to different behaviour and social interactions. ABS (agent based simulation) in early stages of a disease outbreak be more correct.
Zhou et al., 2021	Regression (health data)	Asian Pacific Islanders (API) students reported increases in mental health symptoms and decreases in treatment utilization. COVID-related discrimination is correlated with greater odds of clinically significant mental health symptoms as well decreased help seeking.

Table 6: Literature review part 1 - Measures and behavior in parallel to vaccination

2. Literature review part 2 - Behavior and information before vaccination

Authors	Method	Findings/Results
Andersson et al., 2021	Survey experiment	Vaccine information reduces peoples' voluntary social distancing, hygiene adherence willingness to stay at home.
Bughin et al., 2022	Survey experiment	100% effective vaccination is estimated to be worth 11400€ while effectiveness below 50% with no value. Cost of imposing protective rules 1500-2500€, vs burden of lock down and social distancing is 775€ per citizen per month.
Carrieri et al., 2021	Simulation model	Among the area level indicators, the proportion of waste recycling and the employment rate are found to be the most powerful predictors of high Vaccine hesitancy (VH)
Garattini, Padula, et al., 2020	Theoretical	Budgeting vaccination (instead of pricing), put same unit price for vaccination, set quality threshold, e.g., set vaccination effectiveness at min. 90%.
Lahav et al., 2021	Survey	Strong religious beliefs less likely to become vaccinated, also religious denomination in Israel and identifying with a religion in Japan.
Milstein et al., 2022	Regression (Payment data)	Majority of countries (30/43) with performing payment schemes for Primary care physicians (PCP). 17 countries paid less per vaccination than the income-adjusted average, 13 paid more; 12 used pay-for-performance elements.
Neumann - Boehme et al., 2020	Survey	Vaccination willingness in Europe around 74% while largest concern around vaccination was concern about side effects
S. Kim et al., 2021	Survey	Higher level of COVID-19-related knowledge was associated with higher level of self reported engagement in protective behaviors (most effective interpersonal communication and social media; official sources such US government, CDC, and WHO websites had weaker effects)
Stadnick et al., 2022	Action research	Community Advisory Boards (CABs) for promoting equitable access to COVID-19 testing and vaccination for underserved communities succeeds in conditions of (1) accessible and available services; (2) culturally & linguistically competent programming; (3) investment in trusted community & faith leaders; (4) social safety nets to provide ancillary services.
Vásquez et al., 2021	Survey	Cost and duration of immunity are significant factors in the decision to vaccinate, while the degree of vaccine effectiveness is insignificant.
Wallia et al., 2021	Case Study	By leveraging novel methods of communication and dissemination (social media, partnerships), the gap in care delivery of vaccinations could be addressed and assessed in a rapid period.

Table 7: Literature review part 2 - Behavior and information before vaccination

3. Literature review part 3 – Ways of offering vaccination

Authors	Method	Findings/Results
Barber & West, 2022	Simulation model (synthetic control)	Conditional cash lotteries (CCLs) as used for Ohios vaccination incentive scheme increased vaccination by 1.5%, costed 68 USD per person, and prevented at least one infection for every six vaccinations
Cole, 2021	Survey	Vaccination equity for racial/ethnic groups varied widely by state. Non Hispanic White and Asian patients were more likely to receive the vaccine, whereas Hispanic, Black, and American Indian/Alaskan Native/Pacific Islander were less likely to receive the vaccine.
D. Kim & Lee, 2022	Time series and panel data	Extending the interval between first and second doses of vaccines developed in Europe and the US increase effects of vaccination, but NPI remain important to contain transmission as vaccination is rolled out.
Dai & Song, 2021	Theoretical	Overview of three research streams: (1) supply, (2) demand, and (3) matching supply with demand.
Luyten et al., 2022	Experiment	Vaccine prioritization either for a) virus spreaders and essential workers or b) those who were most at risk because of a pre existing health condition. Other strategies such as "lottery", "first come first served" approach, highest willingness to pay or elderly received little support.
Schulenburg, 2021	Survey	Direct vaccination costs vary between the different mRNA vaccines due to constitution. Operating costs decrease with the size of the vaccination unit due to economies of scale in larger vaccination operations from 2% in large centers, 4% in medium-sized, 8% in small centers, and 41% in GP practices.
Wende et al., 2021	Simulation model	Vaccination schedules based on individual cumulative risk 85% faster than random schedules in preventing deaths, and 57% faster than the German approach, which was based primarily on age and specifc diseases.
Yin & Büyüktahtakın, 2021	Simulation model	Allocating treatment resources proportional to population is sub-optimal and increases infections and deaths, resulting in a high cost for fairness

Table 8: Literature review part 3 – Ways of offering vaccination

Closing remarks

Funding: This research received no external funding.

Institutional Review Board Statement: N.a. since only publicly available data was used.

Data Availability Statement: Not applicable.

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