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Efficiency in Covid-19 Vaccination Campaigns – A comparison across Germany's federal states

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This article investigates the efficiency of the roll-out of Covid-19 vaccinations when vaccines are scarce. Using Germany as an example, we find considerable differences across federal states in terms of efficiency, defined as the ability to get most vaccinations out of a given number of available doses. Back-of-the-envelope calculations for the past five months show that vaccinations would have been 3.7–6.6% higher if all federal states had adopted a similar ratio between vaccinations given and vaccines stored as the most efficient ones. We also find evidence that the integration of doctor's offices into the vaccination campaign significantly increased the share of vaccinations out of a given stocks of vaccine doses.

1 Introduction

On December 31, 2019, the World Health Organization was informed of a new kind of infectious disease that emerged in Wuhan, China.[1] It took only a few months for the virus, later to

[1]https://www.euro.who.int/de/health-topics/health-emergencies/coronavirus-covid-19

be known as SARS-CoV-2, to become pandemic and spread over the globe. By the time this paper was written, the total number of casualties was over 3.4 million worldwide, with over 165 million confirmed cases.[2]

Vaccination is considered a central pillar to stopping the Covid-19 pandemic.[3] New vaccines were developed and approved with impressive speed. Given the scarcity of vaccines, many countries focus on vaccinating the most vulnerable individuals first. Irrespective of the prioritization of groups within the population, the policy goal is clear: roll out the available doses as quickly and efficiently as possible. However, the administrative and logistical challenges are substantial. For instance, according to the European Centre for Disease Prevention and Control, many countries report difficulties in the logistics of the vaccination roll-out, including unexpected delivery failures and the timing of second shots.[4] To overcome these obstacles, vaccine reserves are built. However, when reserves become excessive this can slow down the vaccination roll-out – a situation that can be considered inefficient. When vaccines are scarce the challenge is thus to store just enough doses to guarantee a smooth vaccination campaign. This article analyzes this problem using Germany and its federal states as an example.

Little attention has been paid in the academic literature so far on organization and efficiency of vaccination roll-outs during the Covid-19 pandemic. (*1*) analyze the roll-out in Israel and identify lessons learned from which other countries could benefit, such as the importance of deliveries, prioritization of groups within the population, skilled health care workers, digitization and reaching disadvantaged groups. There are also studies that analyze the prioritization of vaccinations within the population (e.g., to vaccinate first most vulnerable individuals) to prevent as many casualties or hospitalizations as possible (*2, 3*). Our study is closely related to these articles because after there is an agreement on which individuals to vaccinate first, the next step

[2] `https://covid19.who.int/`, data as of May 22, 2021.
[3] `https://www.nature.com/articles/d41586-021-00450-z`.
[4] `https://bit.ly/3uXV7Lk`.

is to actually vaccinate those individuals as quickly as possible. To the best of our knowledge our study is the first to formally analyze the efficiency of a country's vaccination roll-out.

Just as in other countries such as the USA[5] or India[6], the vaccination roll-out in Germany is managed on a regional scale by local government bodies. The respective bodies are Germany's 16 federal states which show noticeable differences in the progress of their respective vaccination roll-outs.[7] Every federal state faces essentially the same problem of determining the optimal level of vaccine reserves to maintain a smooth vaccination campaign. When reserves are too low, appointments have to be re-scheduled and no more shots can be given. When reserves are too high, more vaccinations could be given without compromising second shots. Vaccinations are at a sub-optimal level in both situations.

To evaluate the efficiency of the federal states' vaccination roll-outs it is relevant to systematically compare vaccine deliveries and stocks to vaccinations given. If Federal State A receives less vaccines than Federal State B, all else equal, the vaccination roll-out in A will be slower than in B. However, the roll-out in A might still be quicker than in B when A is closer to the optimal level of reserves. We use so-called Data Envelopment Analyses (DEAs) to identify those federal states which are most efficient in rolling out vaccinations, i.e., those which are able to maintain a smooth vaccination campaign with the lowest vaccine reserves. Efficiency is measured as a ratio of output (vaccinations given) to input (vaccinations delivered and reserves). Thus, the terms inefficiency and excessive reserves are basically used synonymously in our analyses. Moreover, they are interpreted in relative terms, i.e., in the context of a comparison between federal states. In other words, we try to identify a lower bound of vaccination

[5] https://www.nytimes.com/interactive/2020/us/covid-19-vaccine-doses.html

[6] https://geographicinsights.iq.harvard.edu/IndiaVaccine

[7] These federal states are Brandenburg (BB), Berlin (BE), Baden-Wuertemberg (BW), Bavaria (BY), Bremen (HB), Hesse (HE), Hamburg (HH), Mecklenburg Western Pomerania (MV), Lower Saxony (NI), Northrhine-Westphalia (NW), Rhineland-Palatinate (RP), Schleswig-Holstein (SH), Saarland (SL), Saxony (SN), Saxony-Anhalt (ST) and Thuringia (TH). As of May 17, 2021, the share of people having received a first (second) shot ranges from 32% in Saxony (9.6% in Lower Saxony) to 41.1% in Saarland (15.1% in Thuringia), see https://impfdashboard.de/.

efficiency rather than a global optimum.

We identify Bremen, the least populous state, as the overall most efficient federal state. When allowing for decreasing returns to scale in the vaccine inputs (i.e., the higher the number of available doses the more complex the vaccination campaign becomes) Northrhine-Westphalia, Germany's most populous state, shows relatively high efficiencies. Using the shares of vaccinations given relative to deliveries and reserves of these two federal states as benchmarks, one can see that total vaccinations given could have been 3.71–6.58% higher until May 16, 2021. This corresponds to 1,483,388–2,632,971 more vaccinations. If all these doses had been used for first shots, another 1.78–3.16% of the German population could have received their first dose in Germany.

For the efficiency of the roll-out the question *where* the population can receive vaccinations seems to be particularly important. Potential candidates include vaccination centers, hospitals, retail pharmacies or doctor's offices. Especially the integration of the latter into a country's vaccination campaign is widely discussed. For the US, (*4*) emphasize the benefits that integration could have, for instance, in terms of overcoming vaccine "hesitancy" in the population. As a second step of our analyses we thus investigate the effect the integration of doctor's offices had on Germany's vaccination campaign in a fixed effects regression.

Doctor's offices were officially integrated into Germany's vaccination campaign on April 5, 2021. For the period after April 5, we identify a structural break in the share of vaccinations given in relation to vaccines delivered and kept as reserves. This share significantly increases after family physicians received permission to give vaccinations. Even though it cannot be excluded that unobserved factors have led to a reduction in the share of vaccines held as reserves this provides evidence for the notion that the integration of doctor's offices sped up the vaccination campaign.

The paper is structured as follows. The results of the DEA are presented in Section 2. In

Section 3, the results of the analyses of the effect of the integration of doctor's offices into Germany's vaccination campaign are presented. Section 4 concludes. Supplement 1 provides an overview of our data set as well as further information on the DEA-method. Supplements 2 and 3 contain further information on Sections 2 and 3, respectively, including various robustness checks.

2 Results: DEA

Three types of models were computed with different output variables. In models T, 1S and 2S, the respective output variables are the total number of vaccinations, the total number of first shots given and the total number second shots given in week t. The input variable are vaccine deliveries in week t plus vaccine reserves in week $t-1$. A more thorough discussion can be found in Supplement 1.

Table 1 presents the results of the mean DEA scores in Models T, 1S and 2S of DEAs performed for each week of our observation period. Here, constant returns to scale (CRS) are assumed. This assumption is discussed and relaxed below.

Federal State	T	1S	2S
Baden-Wuerttemberg	0.5996	0.5925	0.4584
Bavaria	0.7442	0.7325	0.5488
Berlin	0.7425	0.6899	0.6873
Brandenburg	0.5976	0.549	0.4324
Bremen	0.8625	0.8134	0.689
Hamburg	0.6763	0.6679	0.4929
Hesse	0.6016	0.5974	0.4881
Lower Saxony	0.5701	0.5726	0.3983
Mecklenburg Western Pomerania	0.7499	0.6878	0.4937
Northrhine-Westphalia	0.627	0.6382	0.4454
Rhineland Palatinate	0.7355	0.6646	0.5265
Saarland	0.5788	0.5893	0.4082
Saxony	0.5561	0.5016	0.5446
Saxony-Anhalt	0.6049	0.584	0.4689
Schleswig-Holstein	0.7417	0.6776	0.5376
Thuringia	0.6863	0.6438	0.6567

Table 1: Average efficiency scores for the period December 27, 2020 to May 16, 2021 for DEAs performed on a weekly basis under the CRS assumption using the sum of the vaccine reserves at the end of the previous week and the deliveries in each week as the input variable.

Table 1 shows that Bremen has the highest average DEA score with 0.8625 in model T, 0.8134 in model 1S and 0.689 in model 2S. This indicates that the vaccination roll-out in Bremen is the most efficient in Germany if CRS are assumed.

One might argue that the results of a small federal state such as Bremen with a total population of less than 600,000 are not applicable to larger federal states such as Bavaria or Northrhine-Westphalia with population of 13.8 million and almost 18 million, respectively, and a lower population density. Likewise, Bremen receives fewer vaccine deliveries (see the descriptive statistics in Supplement 1), which potentially eases the organizational burden of the vaccination roll-out. In other words, a vaccination campaign might be susceptible to decreasing returns to scale so that it becomes increasingly difficult to distribute vaccinations the larger the input in vaccines.

Assuming VRS instead of CRS allows for a more flexible relationship between inputs and outputs (production technology) that particularly accounts for decreasing returns to scale. The results of VRS DEAs computed for each week of the observation period are presented in Table 2.

Federal State	T	1S	2S
Baden-Wuerttemberg	0.7363	0.7419	0.6222
Bavaria	0.9478	0.912	0.7507
Berlin	0.8143	0.7442	0.7344
Brandenburg	0.6551	0.6123	0.515
Bremen	1	1	1
Hamburg	0.7268	0.7269	0.5889
Hesse	0.6954	0.6764	0.561
Lower Saxony	0.6912	0.6861	0.486
Mecklenburg Western Pomerania	0.8042	0.7744	0.6238
Northrhine-Westphalia	0.9782	0.9314	0.8258
Rhineland Palatinate	0.8098	0.7378	0.6069
Saarland	0.6517	0.6743	0.5937
Saxony	0.6102	0.5435	0.596
Saxony-Anhalt	0.6502	0.6327	0.5383
Schleswig-Holstein	0.7993	0.7502	0.6273
Thuringia	0.7381	0.6886	0.7269

Table 2: Weekly average DEA efficiency scores for the period December 27, 2020 to May 16, 2021 under the VRS assumption using the sum of the vaccine reserves at the end of the previous week and the deliveries in each week as the input variable.

The results presented in Table 2 show that Bremen is assigned average DEA scores of 1 in every model. This means that Bremen is among the federal states that define the production possibility in every week. Thus, if a more flexible production technology is assumed, the federal state performs even better than with CRS. In contrast to the CRS DEA, larger federal states such as Northrhine-Westphalia are assigned significantly higher DEA scores.

We try to explain which factors are responsible for the different efficiencies in Supplement 2. There, we also present robustness checks for the analyses presented above.

The results presented in Tables 1 and 2 indicate differences in the prioritization of first and second shots between federal states. Apparently, federal states with lower scores in model 1S than in model 2S (e.g, Saxony) focus on full immunization of the population whereas federal states with lower scores in model 2S than in model 1S (e.g., Lower Saxony) seem to prioritize first shots.

To illustrate the potential impact of improvements in efficiency on the progress of the vaccination campaign, a back-of-the-envelope calculation is presented. It is assumed that all federal states have rolled out vaccinations similarly to Bremen or Northrhine-Westphalia in terms of vaccinations given in relation to deliveries and reserves. In doing so, a ratio of total vaccinations given in week t (output) to vaccine deliveries in week t and vaccine reserves at the end of week $t-1$ (input) is computed. Formally, federal state i's share in week t reads

$$s_{i,t} = \frac{\text{vaccinations}_{i,t}}{\text{deliveries}_{i,t} + \text{reserves}_{i,t-1}}. \tag{1}$$

To illustrate the idea, $s_{i,t} = 0.6$ would indicate that in federal state i in week t, 60% of the doses available for vaccination in week t are actually vaccinated whereas the remaining 40% are held back as reserves.

Assuming that all federal states adopt the above ratio for Bremen ($s_{\text{HB},t}$) or Northrhine-Westphalia ($s_{\text{NW},t}$) in each week t, we compute hypothetical vaccinations given per federal state. The results are presented in Table 3.

		Bremen		Northrhine-Westphalia	
federal state	act. vacc	hyp. vacc	%-gain	hyp. vacc	%- gain
HB	357,057	357,057	0	357,057	0%
BB	1,114,386	1,275,510	14.46%	1,240,500	11.32%
BE	1,703,655	1,865,597	9.56%	1,814,618	6.51%
BW	5,268,410	5,633,012	6.92%	5,478,964	4%
BY	6,368,489	6,781,714	6.49%	6,598,418	3.61%
HE	2,967,320	3,203,825	7.97%	3,116,625	5.03%
HH	854,467	936,325	9.58%	910,737	6.59%
MV	794,509	818,114	2.97%	795,706	0.15%
NI	3,817,325	4,066,473	6.53%	3,955,179	3.61%
NW	8,869,664	9,120,334	2.83%	8,869,664	0%
RP	1,970,369	2,086,663	5.90%	2,029,628	3.01%
SH	1,396,932	1,482,686	6.14%	1,442,246	3.24%
SL	523,240	582,458	11.32%	568,479	8.65%
SN	1,912,294	2,161,140	13.01%	2,103,881	10.02%
ST	1,024,732	1,124,923	9.78%	1,094,323	6.79%
TH	1,041,879	1,121,869	7.68%	1,092,088	4.82%
Total	39,984,728	42,617,699	6.58%	41,468,116	3.71%

Table 3: Counterfactual scenario where it is assumed that less efficient federal states adopt $s_{i,t}$ for $i =$ Bremen or $i =$ Northrhine-Westphalia in every week t.

The results presented in Table 3 indicate that over 2.6 million ($+6.58\%$) more vaccinations would have been given until May 16, 2021 if all federal states had adopted $s_{\text{HB},t}$ in each week t. This corresponds to 3.16% of the German population.

A comparison with Northrhine-Westphalia, whose vaccination roll-out is remarkably efficient given the size of the federal states, yields less optimistic, yet noticeable figures. According to the results presented in Table 3, almost 1.5 million more doses would have been vaccinated if all federal states (except for Bremen) had adopted Northrhine-Westphalia's ratio between vaccinations given and reserves and deliveries. This still corresponds to 1.78% of the entire population and constitutes a plus of around 3.71%.

3 Vaccination at Doctor's Offices

Since April 5, 2021, doctor's offices are integrated into Germany's vaccination campaign.[8] In the light of increasing vaccinations given at vaccination centers and vaccine deliveries in that period, an empirical analysis on the effect of that integration on the *efficiency* of the vaccination roll-out is appropriate.

This is because the effects of the integration of doctor's offices into the vaccination campaign may be ambiguous. The share of doses being vaccinated in relation to those being stored ($s_{i,t}$ in Equation (1)) may increase when more people decide to get vaccinated because they trust their family physician or because it is easier for them to access a doctor's office in their close proximity (see, e.g, (*4*)). Moreover, doctor's offices may have limited opportunities to store vaccine doses. It is, however, also possible that the measure simply leads to a redistribution. That is, individuals receive a shot from their family physician which they would have otherwise received at a vaccination center. The vaccination roll-out could even be hindered if the necessary planning involved in supplying doctor's offices leads to further inefficiencies.

Unfortunately, no systematic historical data on vaccine deliveries to doctor's offices in Germany were available to the authors by the time this paper was written. It is therefore attempted to identify the effect at hand using the following fixed effects panel regression:

$$s_{i,t} = \alpha + \beta t + \delta D_{\text{April 5}} + \nu_i + \epsilon_{i,t}. \tag{2}$$

The dependant variable in Equation (2), the share $s_{i,t}$, is defined as in Equation (1). Note that this is the ratio between (unweighted) output and input of model T presented in Section 2. The observed shares are depicted in Figure 1 for each federal state.

Figure 1 illustrates that $s_{i,t}$ shows substantial fluctuations over time in most federal states

[8] `https://www.bundesregierung.de/breg-en/news/vaccination-summit-1879550`.

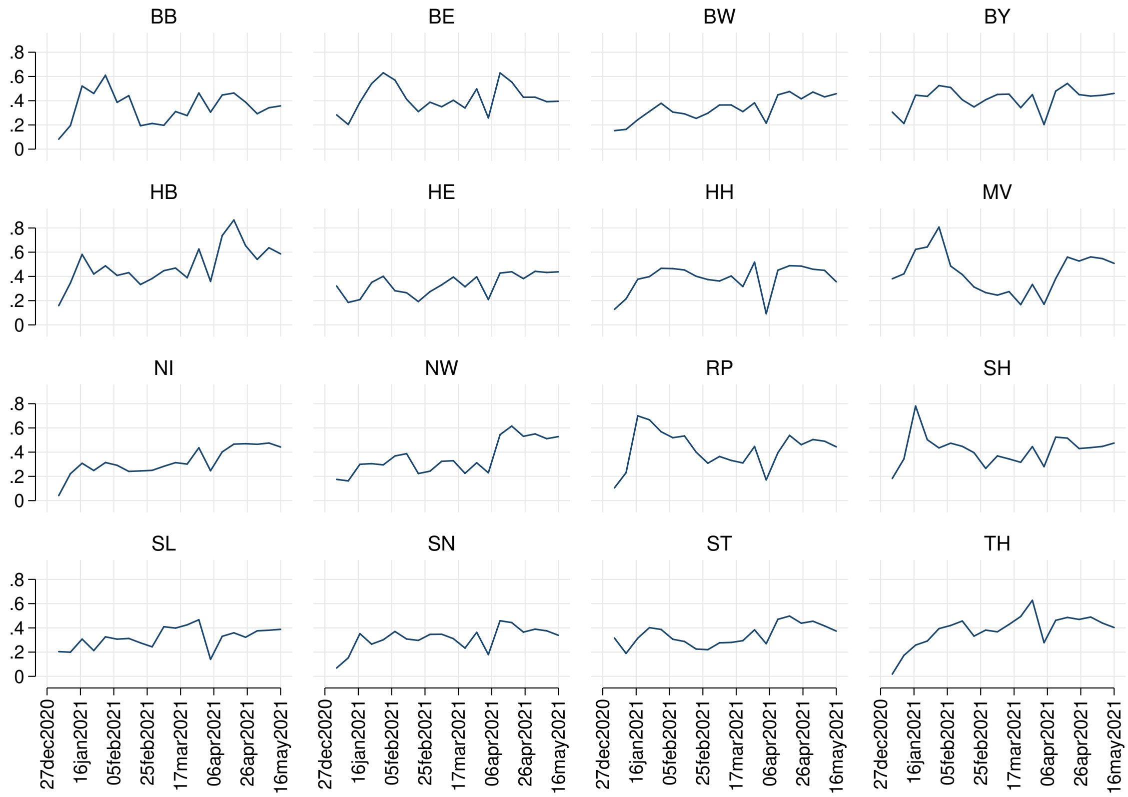

Figure 1: The share of vaccinations given in week t in relation to deliveries in week t and reserves in week $t-1$ $\left(s_{i,t} = \frac{\text{vaccination}_{i,t}}{\text{deliveries}_{i,t}+\text{reserves}_{i,t-1}}\right)$ for all federal states.

and differs remarkably between them. For instance, in Bremen (HB) the share relatively quickly increases to values over 0.4 and even jumps to over 0.8 whereas in Saarland (SL) the share never exceeds 0.5.

In Equation (2), $s_{i,t}$ is explained by a time trend t, the variable $D_{\text{April 5}}$ that takes the value 1 for the period after April 5, 2021, and 0 otherwise as well as a federal state specific fixed effect v_i. The latter controls for time-invariant effects specific to a federal state. This approach enables an investigation of whether the integration of doctor's offices into the vaccination campaign potentially improved efficiency of the vaccination campaign for Germany on average. The results are presented in Table 4.

	(1)	
$D_{\text{April 5}}$	0.115^{**}	(4.04)
$Time\ trend$	0.000848	(0.31)
Constant	0.334^{***}	(13.56)
Observations	320	
R^2	0.344	
R^2 adjusted	0.307	

t statistics in parentheses

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 4: Output table for Equation (2).

The results presented in Table 4 indicate that there is a statistically significant structural break on April 5, 2021, for Germany. That is, $s_{i,t}$ increases by 11.5% on average in the period after April 5, 2021, compared to the period prior to that date. In other words, the share of doses held back as reserves decreases by the same fraction on average. This means that, on average, 11.5 *more* out of 100 available doses – measured by vaccine reserves plus vaccine deliveries – are given each week.

This structural break might be driven by doctor's offices being integrated into the vaccination campaign. However, it cannot be excluded that there may be other factors that occurred during that period that also increase $s_{i,t}$. A possible other explanation would be the findings of (*5*) that a 12-week rather than a shorter timespan between first and second shots of the vaccine produced by Astra-Zeneca does not reduce protection against Covid-19. This might have led decision makers to reduce stock holdings of Astra-Zeneca's vaccine, i.e., all else equal, to an increase in $s_{i,t}$. If this happened (with some delay) in the period after April 5, 2021, the effect of the integration of doctor's offices into the vaccination campaign would be overestimated.[9]

The results presented above imply that, on average, the integration of doctor's offices into

[9] One might also argue that decision makers intentionally increased reserves in anticipation of the integration of doctor's offices into the vaccination campaign to maintain a smooth vaccination roll-out at vaccination centers. While this might potentially be true, it seems unrealistic to assume that decision makers are able to correctly anticipate the integration of doctor's offices into the vaccination campaign but fail to anticipate future deliveries.

the vaccination campaign has led to an increase in $s_{i,t}$. However, this does not imply that every federal state exhibits a statistically significant structural break in the period after April 5, 2021. Moreover, on average, based on the results presented in Table 4 no statistically significant time trend can be diagnosed. What the results do indicate is that for Germany as a whole, there is a statistically significant structural break. This seems to be driven by some federal state that exhibit a relatively strong structural break (e.g., NW), whereas for other federal states no such effect may be diagnosed. These findings are supported by various robustness checks that are presented in Supplement 3.

4 Discussion

This study is a first attempt to systematically analyze the efficiency of the Covid-19 vaccination roll-out in different regions of a country. This exercise allows one to identify a lower bound of efficiency of that country's vaccination campaign. Similar analyses can be performed for other countries as well, especially because data requirements are minimal. We used Germany as an example. Several DEAs were performed to identify the most efficient among Germany's federal states. Our results indicate that by the time this paper was written Bremen apparently defines the efficiency frontier in most model variants. Among the larger federal states, Northrhine-Westphalia seems efficient. With VRS, this federal state has relatively high average efficiency scores whereas under CRS its average scores are relatively low.

Our results on the effect of integrating family physicians into the vaccination campaign indicate an important avenue on how vaccination might be sped up. However, to clearly identify that effect further analyses using data on vaccines delivered to and vaccinations given by family physicians over time broken down by federal states would be helpful.

There are numerous venues for future research. First, the determination of the factors which lead to excessive reserves in a country still requires further analysis. Second, a crucial next step would be to analyze absolute rather than relative efficiencies as this would allow for global improvement of the vaccination roll-out. In doing so, a richer data set including, for instance, systematic information on the expected dates of future deliveries, would be necessary. This problem could be, e.g., analyzed in an (s,S)-model (see, e.g., (*6*)) by calculating the optimal level of reserves based on the costs of an additional delivery and the costs of keeping reserves in stock. Quantifying the latter is a non-trivial exercise because one would have to compare the benefits of a first with that of a second vaccination. Moreover, a more sophisticated data base would be necessary that involves *planned* vaccine deliveries. Third, due to the lack of data we could not directly identify the shares of the different age groups which received vaccinations. In particular, in terms of the death toll of the pandemic, quick vaccination of the most vulnerable groups is of utmost importance and another aspect of the efficiency of the vaccination campaign. Fourth, further insights could be generated by examining the relative performance of different vaccination centers within the federal states. Fifth, DEAs cannot only be computed to compare the relative efficiencies of different areas within a country, but also to compare the efficiency of vaccination roll-outs across different countries. Sixth, incorporating data on, e.g., health care workers, the number of vaccination sites, demographic and geographic factors into the analyses can provide further valuable insights.

We think that analyses on the efficiency of vaccination roll-outs play an integral role in overcoming the Covid-19 pandemic. Avoiding excessive reserves is crucial – a vaccine that is unused cannot save lives. That countries handle the vaccine doses available to them as efficiently as possible seems to be particularly important against the background of pronounced vaccine scarcities in low-income countries (e.g., (*7*)). Even if some of these analyses will only be finished after the recent Covid-19 pandemic they will still be relevant in the future if new infectious diseases arise. Covid-19 has corroborated the importance of being prepared in order to take quick and sound action.

Supplement 1: Data and Methodology

Our data set is comprised of two sources of data. Data on vaccine deliveries are available on the website of the Federal Ministry of Health.[10] Data on daily vaccinations are published by the Robert-Koch-Insitute (RKI).[11] On the official website of the RKI, only recent data on vaccinations are available. However, historical data are made available via github.com by members of the German public broadcaster ARD.[12] Our observation period is December 27, 2020 (when the first delivery arrived) to May 16, 2021.

Before we showcase key descriptive statistics some comments on the data are in order. First, it is difficult to capture the decision makers' expectations and evaluate *global* efficiency based on data on actually realized deliveries because the roll-out is necessarily based on planned deliveries. However, every federal states faces the same uncertainty. This makes it possible to draw conclusions regarding *relative* efficiency. This is the goal of this study. Second, RKI revises its data ex post. RKI thus reports zero vaccinations on a federal state-level for some days even though positive aggregated vaccinations for Germany are reported. Missing vaccinations are apparently attributed to subsequent days. This means that the data we present here might differ slightly from aggregated real-time data published by RKI. However, this problem neither affects the results of the DEAs presented in Section 2 nor the estimations of Section 3 in the main text because these are based on weekly data. For the same reason, our analyses are not affected by holidays of individual federal states that could potentially affect the vaccination campaign.

Figure 2 shows daily vaccine deliveries and vaccinations given for the period December 27, 2020 to May 16, 2021 in Germany. One can see that deliveries are relatively infrequent

[10] https://www.bundesgesundheitsministerium.de/coronavirus/faq-covid-19-impfung.html

[11] https://impfdashboard.de/

[12] https://github.com/ard-data/2020-rki-impf-archive/tree/master/data/9_csv_v2

and their magnitude varies. This corroborates the organizational challenge of the vaccination campaign, especially against the background that it is necessary to give two shots to achieve full immunization.

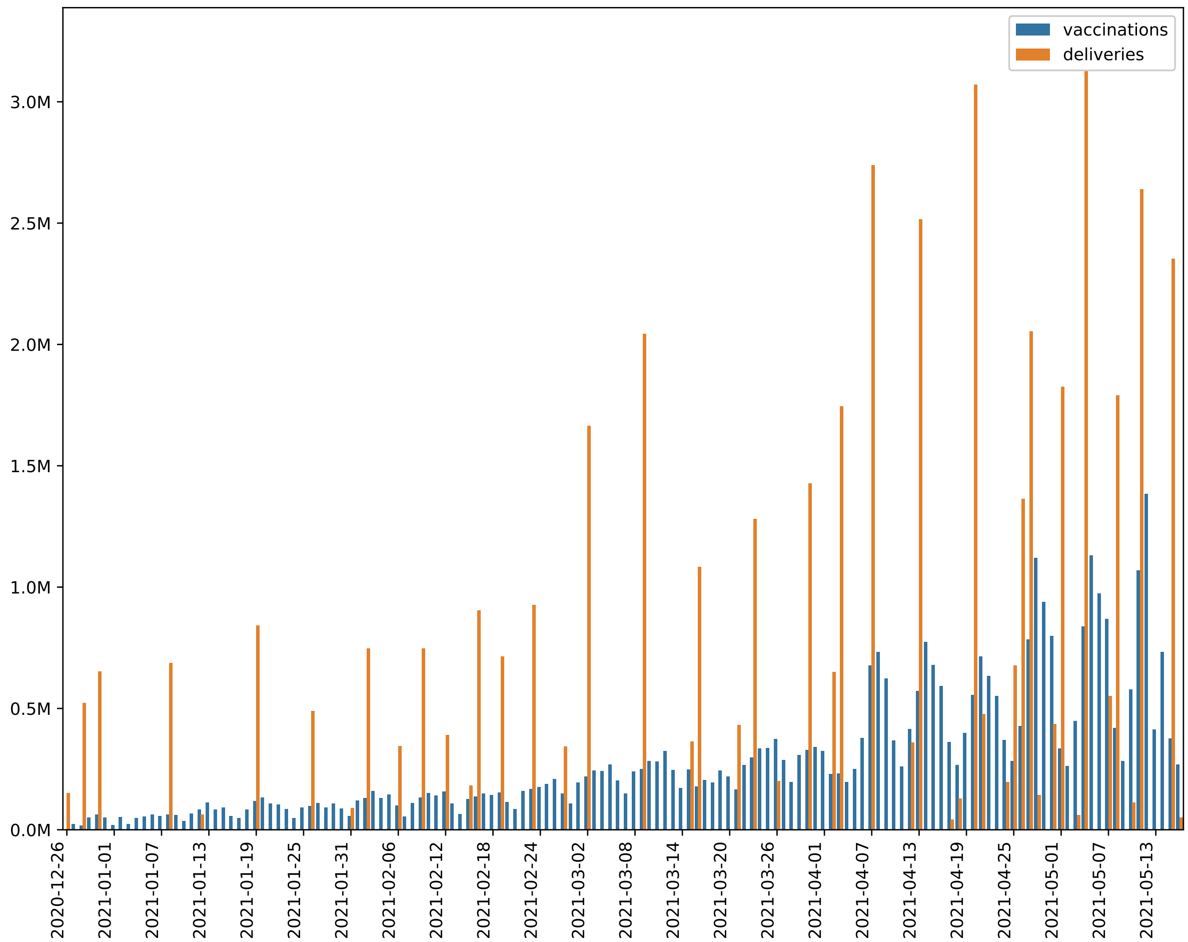

Figure 2: Daily number of vaccinations and deliveries for Germany based on RKI's aggregated data for Germany as a whole.

In Figure 3 daily vaccine deliveries and vaccinations given are depicted for each federal state for the period December 27, 2020 – May 16, 2021.[13] Again, one can see that each federal state received fewer large deliveries and vaccinations are rolled out accordingly. Remarkably, Saarland (SL) received a delivery of over 80,000 vaccines at the end of March. These deliveries,

[13]Recall that observations of zero or even negative vaccinations are due to errors in the data, which are corrected by RKI ex post.

however, seem to have barely affected contemporary vaccinations. Given Saarland continued to receive relatively high deliveries in the subsequent period, this indicates that reserves built up.

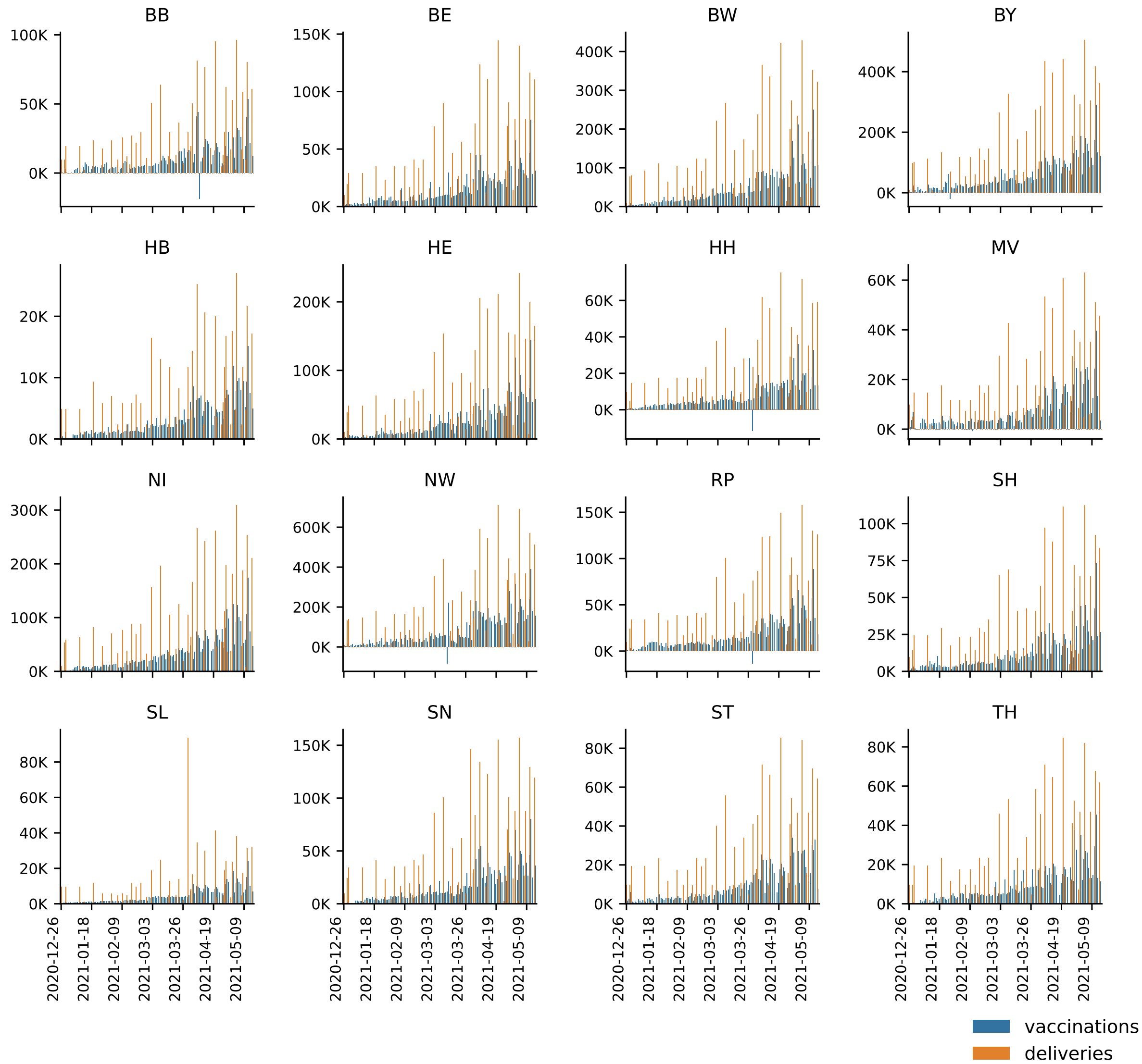

Figure 3: Daily number of people vaccinated and deliveries by Federal State.

Table 5 presents an overview on total deliveries, vaccinations broken down by first and second vaccinations and storage quotas for the first quarter of 2021. The storage quota relates deliveries to total vaccinations. For instance, Bremen (HB) had 6,164 doses on stock, which was approximately 4.66% of total deliveries. Note that Table 5 provides a snapshot: storage quotas are inflated in some federal states (e.g., Saarland (SL)) that received large shipments by the end of the quarter whereas other did not.

Federal State	Deliveries	Total vaccinated	First	Full	Storage quota
HB	132,255	126,091	90,234	35,857	4.66%
TH	432,150	403,299	280,682	122,617	6.68%
BE	697,200	635,103	427,101	208,002	8.91%
BB	472,590	429,998	328,564	101,434	9.01%
SH	550,575	494,930	378,776	116,154	10.11%
NI	1,503,825	1,328,867	920,694	408,173	11.63%
HH	347,325	301,837	211,080	90,757	13.10%
BY	2,569,635	2,232,881	1,516,433	716,448	13.11%
BW	2,085,075	1,798,007	1,253,952	544,055	13.77%
HE	1,188,420	1,022,298	691,217	331,081	13.98%
RP	790,185	676,868	495,688	181,180	14.34%
ST	418,200	351,265	251,865	99,400	16.01%
NW	3,363,300	2,739,983	1,913,865	826,118	18.53%
MV	300,225	234,839	159,250	75,589	21.78%
SN	856,875	654,525	405,999	248,526	23.61%
SL	266,340	176,290	129,287	47,003	33.81%

Table 5: Summary statistics for q1.2021 by Federal State.

A central goal of our study is to identify systematic excessive reserves (see Section 1 in the main text). Our analyses aims to identify those federal states that manage an uninterrupted vaccination campaign with as little reserves as possible. It is thus illuminating to investigate vaccine reserves more closely. Figure 4 presents vaccine reserves in Germany for the period December 27–May 16, 2021.[14] It shows that towards the end of the observation period, there are almost 6 million doses on stock. This constitutes jabs for over 7% of Germany's population (83,190,556 as of September 30, 2020[15]). One can see a sawtooth-like shape of deliveries and

[14]Recall that daily data have to be interpreted with care due to ex post revisions of RKI. This also applies to Figure 5.

[15]`https://bit.ly/3bOABoR`

vaccinations given, however, the level of reserves drastically increases over time.

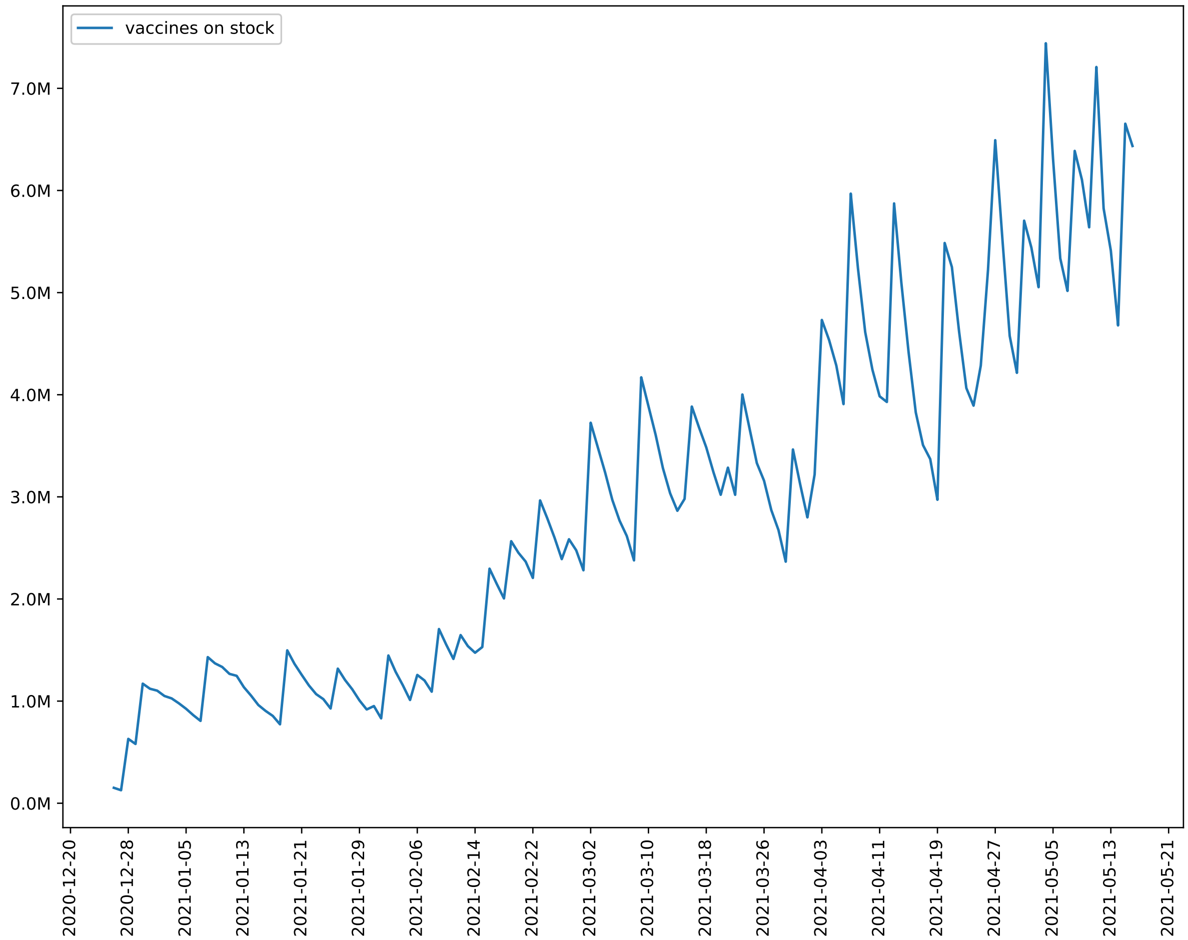

Figure 4: Daily number of vaccines on stock.

Figure 5 presents vaccine reserves broken down by federal states for the entire observation period. Overall, the figure shows the same picture as for Germany as a whole. Even though some federal states such as Bremen (HB) apparently reduced vaccine reserves to some degree during the observation period towards mid May every federal state seems to build up substantial vaccine reserves.

Figure 5: Daily number of vaccines on stock by Federal State.

index	count	mean	std	min	25%	50%	75%	max
BB	18	0.47	0.22	0.24	0.31	0.39	0.58	0.88
BE	18	0.35	0.14	0.16	0.25	0.32	0.43	0.68
BW	18	0.56	0.32	0.21	0.28	0.5	0.76	1.34
BY	18	0.35	0.12	0.19	0.24	0.33	0.41	0.55
HB	18	0.28	0.16	0.03	0.13	0.29	0.41	0.55
HE	18	0.56	0.28	0.21	0.3	0.51	0.78	1.05
HH	18	0.39	0.16	0.2	0.23	0.4	0.43	0.82
MV	18	0.36	0.21	0.07	0.18	0.26	0.56	0.68
NI	18	0.62	0.34	0.19	0.28	0.59	0.92	1.12
NW	18	0.54	0.3	0.14	0.19	0.59	0.75	1.08
RP	18	0.31	0.11	0.17	0.21	0.27	0.41	0.51
SH	18	0.31	0.12	0.15	0.23	0.26	0.4	0.56
SL	18	0.59	0.29	0.21	0.34	0.53	0.81	1.2
SN	18	0.58	0.25	0.28	0.35	0.55	0.74	1.12
ST	18	0.52	0.23	0.21	0.26	0.55	0.69	0.9
TH	18	0.46	0.35	0.13	0.23	0.38	0.51	1.55

Table 6: Summary statistics on reserves per first dose given for the period January 11, 2021 to May 16 by Federal State

Finally, Table 6 presents descriptive statistics on reserves per first doses given. For instance, in Brandenburg an average of 0.47 doses were held as reserves per first shot given with a median of 0.39. Consistent with the observations described above, Bremen shows relatively low median reserves whereas countries such as Saarland (SL) and Lower-Saxony (NI) have relatively high median reserves.

The descriptive statistics presented above provide a broad overview on the reserves of the federal states. Next, the method of Data Envelopment Analysis (DEA) will be described.

A DEA is a method to compare the relative efficiencies of different Decision Making Units (DMUs). The method was formalized by (*8*). Since then, it has been used to analyze performance of water (*9*) or electricity (*10*) suppliers or railroad firms (*11*). In the health care sector, the method has been applied to hospitals (*12, 13*) and also to vaccination centers ((*14*)). The concept is closely related to cost-effectiveness and cost-utility analyses in health economics (*15, 16*). (*17*) offer an extensive review of the various applications and refinements of the technique.

In a DEA, efficiency is measured as a deterministic ratio between inputs and outputs. In the original formulation of (*8*), there are $j = 1, \dots, n$ DMUs with $r = 1, \dots, s$ outputs and $k = 1, \dots, m$ inputs. The known values of output r and input k of DMU j are denoted y_{rj} and x_{kj}, respectively. To find the most efficient among the n DMUs, the following program can be used

$$\begin{aligned} \max_{u_r, v_k} \quad & h_0 = \frac{\sum_{r=1}^{s} u_r y_{r0}}{\sum_{k=1}^{m} v_k x_{k0}} \\ \text{s.t.} \quad & \frac{\sum_{r=1}^{s} u_r y_{rj}}{\sum_{k=1}^{m} v_k x_{kj}} \leq 1 \; \forall j = 1, \dots, n, \\ & v_r, u_k \geq 0 \; \forall r = 1, \dots, s, k = 1, \dots, m. \end{aligned} \tag{3}$$

The weights v_r, u_k are endogenously determined by comparison of all DMUs included as a reference. The problem can then be reformulated to yield a program that is solvable via linear programming. A detailed derivation can be found in (*8*) or any textbook (e.g., (*18*)).

In addition to a DEA with constant returns to scale (CRS), we will perform DEAs with variable returns to scale (RCS). In contrast to a CRS DEA, where the production possibility formed by the most efficient DMUs, in a VRS DEA the production possibility frontier is non-linear and defined by multiple DMUs. The concept of VRS DEA goes back to (*19*) and is sometimes also referred to as the BCC-model. Note that the BCC-model has a slightly different optimization problem; for a more detailed overview, see Chapter 2 in (*20*).

The question whether CRS or VRS is assumed is especially important in applications in the health care sector (*20, Ch. 16.4.4.2*). The importance of this assumption is corroborated by (*14*) who study vaccination roll-outs in vaccination centers in Bangladesh. According to their (ibid.) results, roughly 80% of the centers in their sample operate with increasing returns to scale, 15% with decreasing and only 5% with constant returns to scale. This indicates that allowing for a more flexible production function appears to be valid in our application. To illustrate the difference, Figure 6 presents the results of a single DEA computed under the CRS and VRS assumptions, respectively, for the entire period December 27, 2020, to May 02, 2021.

Figure 6 illustrates that under CRS the production frontier (here: defined by Bremen (HB)) is a straight line. In contrast, the dotted efficiency frontier has two nodes defined by Bremen (HB) and Northrhine-Westphalia (NW).

The DEA is an appropriate method to analyze the relative efficiency levels of the vaccination roll-out of Germany's federal states for the following reasons. The DEA is a non-parametric method, i.e., no assumptions on the functional form of the production function have to be imposed. Second, the DEA is used to analyze the relative performance of not-for-profit entities. In our case, the overall policy-goal is to maximize output, i.e., to roll out as many vaccinations possible given the available doses. This is in contrast to, e.g., a profit-maximizing firm that takes into account price-effects of its output-choice.

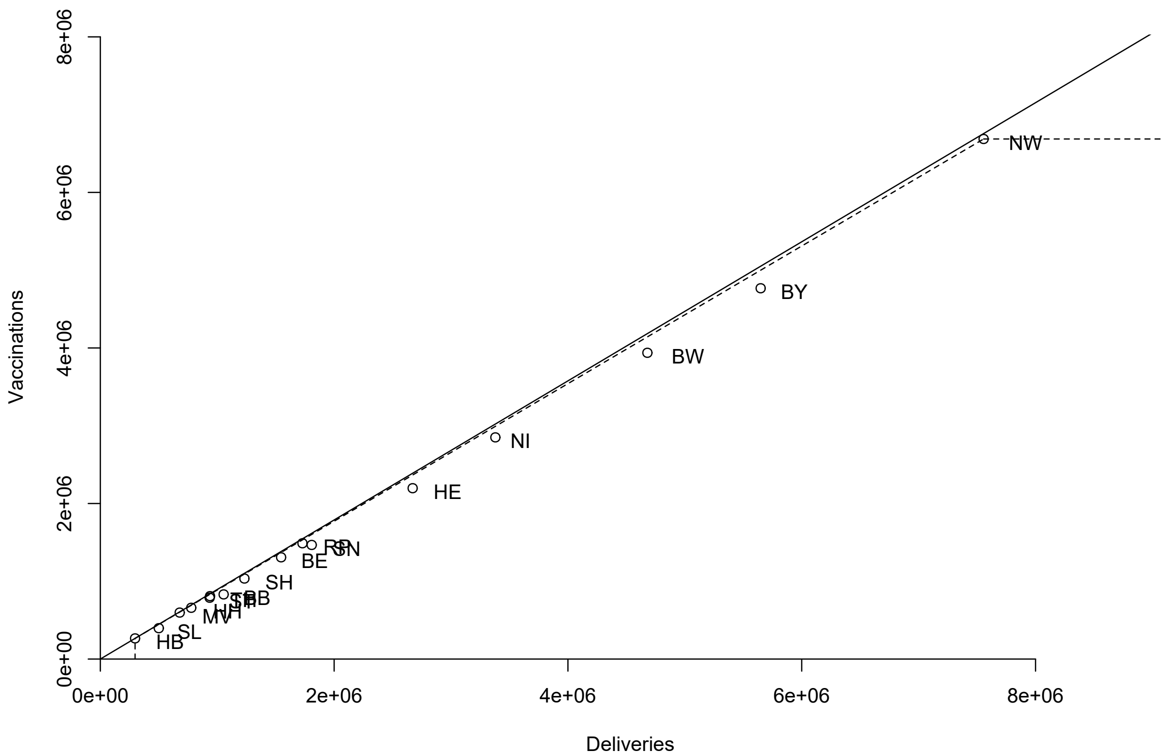

Figure 6: Plot of CRS (solid) and VRS (dashed) efficiency frontiers using aggregated data for the period December 27-May 02, 2021.

Before we discuss the input and output measures chosen for the DEAs presented in the main text, it is appropriate to provide more information on the vaccine doses available for vaccination during the observation period. In Germany, two mRNA-based vaccines produced by Biontech/Pfizer and Moderna were used and one vector-based vaccine produced by Astra-Zeneca. Towards the end of the observation period, a second vector-based vaccine produced by Johnson&Johnson was approved. According to the guidelines in Germany, immunization with mRNA-based vaccines (the vaccine produced by Astra-Zeneca) is achieved with two shots that have to be given within 6 weeks (12 weeks). Only one dose of the vaccine produced by Johnson&Johnson is required.[16]

[16]Official guidelines are provided by the Federal Institute of Vaccines and Biomedicines (Paul-Ehrlich-Institute), `https://bit.ly/2Qud8le`; an overview of the relevant information on storage requirement can be found,

Three types of models were computed with different output variables. In models T, 1S and 2S, the respective output variables are the total number of vaccinations given, the total number of first shots given and the total number second shots given in week t.[17] Comparing the results of models 1S and 2S allows for an identification of the prioritization of federal states. A federal state that has high scores in model 2S but performs poor in model 1S can be considered to prioritize full immunization of the population.[18]

The input variable is the sum of vaccine deliveries in week t and vaccine reserves in week $t-1$. This variable approximates the amount of doses available for vaccination in week t. Recall that our goal is to analyze *relative* rather than *absolute* efficiency. Thus, even though this variable potentially overestimates the available doses in absolute terms (e.g., because doses arriving towards the end of week t might not be available for vaccination in week t) it does not systematically bias our results because every federal state is affected in the same way (see the fluctuations in deliveries presented in Figure 3).[19]

Evaluating the scores of a single DEA, however, has caveats because the results are not robust to variations in the observation period. Large deliveries to a federal state (or the lack thereof) towards the end of the respective observation period can lead to relatively high (or low) inputs in relation to output compared to federal states that did not (or did) receive larger shipments thus biasing DEA scores. To overcome this problem DEAs are computed for multiple periods. A federal state can then be considered efficient if it receives high scores in many periods. A further advantage of examining the results of multiple DEAs is that the results become more robust against outliers resulting from, e.g., errors in the data, in general.

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e.g., here: `https://bit.ly/2RmHy9J`.

[17]The observation period for model 2S starts on January 17, 2021, the day the first second shot was recorded.

[18]It is beyond the scope of this paper to discuss whether it is more appropriate to focus on first or second shots. This debate is located in the medical, ethical and political domain.

[19]The results are robust to variations in the input variable. As an example, the results of DEAs computed with vaccine reserves in $t-1$ are presented in Supplement 2.

Supplement 2: DEA

This section provides more detailed information on the results presented in Section 2 in the main text.

Given the little information that is available regarding the administrative processes of the vaccination roll-out in the different federal states, it is difficult to pinpoint certain aspects where federal states' organization of the vaccination roll-out differs. Some information are provided by the media. Unfortunately, the following sources are only available in German language.

One explanation is that first shots are intentionally hold back (in relation to the practices in other federal states) for future appointments.[20] Further aspects where differences are documented between the federal states include the handling of appointments of the different priority groups[21], the use of more efficient syringes[22] and the administrative process of appointment allocations[23]. If there are frictions in these processes, appointments could be made or re-scheduled more flexibly, which would result in more people being vaccinated and less reserves.

The influence of diminishing returns to scale was controlled for in the VRS DEA. However, there are further factors potentially affecting the results.

It is documented that there were occasional failures to deliver vaccines to certain areas.[24] Even though these are out of the control of the decision makers, it is unlikely that these delivery failures to individual federal states systematically affects the DEA scores over a period of over 4 months. The same holds for large-scale delivery failures of the vaccine of Astra-Zeneca.[25] Moreover, the delivery failure of Astra-Zeneca's vaccine affected Germany as a whole so that it should not affect the relative efficiencies of the federal states' vaccination roll-outs.

[20] https://bit.ly/2RoBAoO
[21] https://bit.ly/3ob1Leu
[22] https://bit.ly/3hyfDyj
[23] https://bit.ly/3tFoi4h
[24] See, e.g., https://bit.ly/3uGEIul
[25] https://www.tagesschau.de/ausland/astrazeneca-eu-kommission-101.html

One could argue that it is more difficult for the elderly to make and keep their appointments. This means that the broader the range of age cohorts eligible of being vaccinated the more strongly this could affect the DEA scores because, e.g., it requires more effort to vaccinate the elderly.[26] However, it does not seem to be the case that demographics largely impact our results. Despite some overlaps, the federal states' age profiles do not seem to affect the results of our DEA.[27] The following example illustrates this. If demographics had a significant impact on the relative success of the federal states' vaccination roll-outs, federal states with a younger population such as Hamburg (HH) with an average age of 42.1 would have an advantage over those with an older population such as Thuringia (TH) with an average age of 47.4 years. Hamburg and Thuringia have about the same population while Hamburg is significantly smaller in terms of area. However, according to the results presented in Tables 1 and 2 in the main text Hamburg is not unambiguously more efficient than Thuringia.

By the same token, our results do not seem to be largely driven by the federal states' geography. For instance, Bremen (HB), the most efficient federal state, and Saarland (SL), among the federal states with the lowest efficiency scores, are both relatively small federal states. However, the scores of the federal states with the lowest population density, Mecklenburg Western Pomerania (MV) and Brandenburg (BB) might be driven by the countries' geographies at least to some extent. Note that Mecklenburg Western Pomerania is assigned relatively high scores in model T (see Tables 1 and 2 in the main text), which means that the federal state performs relatively well despite its dispersed population, anyway. In these countries one would expect that it is relatively difficult for people in rural areas to reach vaccination centers and that doctor's offices are more efficient distributors of vaccination than large vaccination centers. Indeed,

[26]In the first quarter the majority of vaccinations were given to the groups with highest (aged 80+) and second highest (aged 70-79) priority. Note that in the official regulation ("CoronaImpfV") priority groups within the population are not only defined by age but also by other factors, such as prior diseases, social relevance or exposition to infected people. The official regulation can be found here: `https://bit.ly/2TbIpdR`.

[27]`https://bit.ly/349YNhb`.

our analyses in Supplement 3 provide evidence that the integration of doctor's offices into those country's vaccination campaigns might have substantially increased efficiency.

In the remainder of this supplement, a DEA with a different input and another time period is presented to demonstrate the robustness of the results presented in the main text. Tables 7 and 8 present the average DEA scores of CRS and VRS DEAs computed for the period December 27, 2020 to May 02, 2021 with only vaccine reserves in week $t-1$ as the input variable (rather than vaccine reserves in $t-1$ plus vaccine deliveries in week t). Again, the results remain largely unchanged.

Federal State	T	1S	2S
Baden-Wuerttemberg	0.4034	0.4054	0.351
Bavaria	0.6143	0.6166	0.528
Berlin	0.5927	0.5619	0.6497
Brandenburg	0.4338	0.403	0.331
Bremen	0.7734	0.7618	0.6686
Hamburg	0.5085	0.518	0.434
Hesse	0.3965	0.3906	0.4123
Lower Saxony	0.3655	0.3696	0.3054
Mecklenburg Western Pomerania	0.5884	0.5268	0.4762
Northrhine-Westphalia	0.446	0.4632	0.3361
Rhineland Palatinate	0.6043	0.5677	0.4368
Saarland	0.3995	0.4157	0.3416
Saxony	0.3762	0.3531	0.4053
Saxony-Anhalt	0.3829	0.3863	0.3411
Schleswig-Holstein	0.5949	0.5718	0.4122
Thuringia	0.5377	0.5193	0.5635

Table 7: Average efficiency scores for the period December 27, 2020 to May 02, 2021 for DEAs performed on a weekly basis under the CRS assumption using vaccine reserves at the end of the previous week as the input variable. Models T, 1S and 2S use total, first and second shots given as the respective output variable.

Federal State	T	1S	2S
Baden-Wuerttemberg	0.6272	0.664	0.5192
Bavaria	0.9522	0.9226	0.739
Berlin	0.7615	0.719	0.7638
Brandenburg	0.5426	0.5277	0.4046
Bremen	0.9739	0.9739	0.9722
Hamburg	0.6124	0.6381	0.5096
Hesse	0.5512	0.5425	0.5014
Lower Saxony	0.5698	0.5785	0.4005
Mecklenburg Western Pomerania	0.6942	0.6851	0.5614
Northrhine-Westphalia	1	0.9411	0.8125
Rhineland Palatinate	0.7721	0.7305	0.574
Saarland	0.4985	0.5251	0.4808
Saxony	0.4905	0.4577	0.4975
Saxony-Anhalt	0.4846	0.5032	0.411
Schleswig-Holstein	0.7335	0.7323	0.555
Thuringia	0.6419	0.6184	0.6908

Table 8: Weekly average DEA efficiency scores for the period December 27, 2020 to May 02, 2021 under the VRS assumption using the vaccine stock at the end of the previous week as the input variable. Models T, 1S and 2S uses total, first and second shots given as the respective output variable.

Supplement 3: Estimation

In this supplement, we present an alternative estimation to analyze the effect of the integration of doctor's offices into Germany's vaccination campaign. The following fixed effects regression is estimated:

$$s_{i,t} = \alpha + \beta t + \gamma_i D_i \times t + \delta D_{\text{April 5}} + \nu_i + \epsilon_{i,t}. \tag{4}$$

In Equation (4), the share $s_{i,t}$ is explained by a time trend, a federal state dummy D_i interacted with the time trend and the dummy variable $D_{\text{April 5}}$ which takes the value 1 in the period starting on April 5, 2021 and 0 otherwise. Federal state-specific fixed effects are denoted ν_i. This allows us to disentangle how the share of vaccinations given in week t in relation to deliveries in week t and reserves in week $t-1$ evolves over time in the different federal states. The fixed effects are chosen such that the effect of the interaction term $D_i \times t$ has to be interpreted relative to the federal state Bremen (HB), as will be explained in more detail below. The results are presented in Table 9.

	(1)	
$D_{\text{April 5}}$	0.115**	(3.95)
$Time\ trend$	0.0105***	(5.68)
BB × $Time\ trend$	-0.0155***	(-2.71e+14)
BE × $Time\ trend$	-0.0148***	(-4.47e+14)
BW × $Time\ trend$	-0.00452***	(-1.45e+14)
BY × $Time\ trend$	-0.0134***	(-4.30e+14)
HE × $Time\ trend$	-0.00808***	(-1.71e+14)
HH × $Time\ trend$	-0.0112***	(-2.92e+14)
MV × $Time\ trend$	-0.0203***	(-5.90e+14)
NI × $Time\ trend$	-0.00197***	(-6.21e+13)
NW × $Time\ trend$	0.0000746***	(2.38e+12)
RP × $Time\ trend$	-0.0166***	(-4.39e+14)
SH × $Time\ trend$	-0.0164***	(-5.21e+14)
SL × $Time\ trend$	-0.0103***	(-3.26e+14)
SN × $Time\ trend$	-0.00860***	(-2.75e+14)
ST × $Time\ trend$	-0.00940***	(-2.95e+14)
TH × $Time\ trend$	-0.00298***	(-9.50e+13)
Constant	0.334***	(26.79)
Observations	320	
r2	0.419	
r2 adjusted	0.354	

t statistics in parentheses
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 9: Output table for Equation (4).

The results indicate that the share $s_{i,t}$ is significantly higher (1%-level) in the period after April 5, which means that, on average, there is a structural break. The order of magnitude of the effect is the same as that presented in the main text. Note that this effect can be driven by doctor's offices being integrated into Germany's vaccination campaign, even though we cannot exclude that other factors also affected the results (see the discussion in the main text).

According to the results presented in Table 9 the share $s_{i,t}$ evolves over time. Each subsequent week, the share $s_{i,t}$ increases by 0.0105 plus the coefficient of the federal state dummy interacted with the time trend.[28] For instance, in Northrhine-Westphalia (NW) the share of vaccinations given in week t in relation to deliveries in week t and reserves in week $t-1$ increases by approximately $0.0105 + 0.0001 = 0.0106$ per week. Likewise, e.g., in Brandenburg (BB) that share *decreases* by $0.0155 - 0.0105 = 0.005$ per week (see Figure 1 in the main text).

To completely interpret the results, consider the federal state Bremen. The constant 0.334 can be interpreted as the starting value of the share $s_{\text{HB},t}$ for the federal state. Week $t = 1$ in our sample is the last week of December, 2020. Subsequently, i.e., in calender weeks $t \in [1, 2, \dots, 19]$ of 2021, that share increases by 0.0105 per week. For weeks 14–19, i.e., the calender weeks starting on April 5, 2021, the level of $s_{\text{HB},t}$ increases further by 0.115. Thus, in the last week, the average effect assigned to Bremen would be 0.6485.

Whereas we observe a clear time trend in the data for Bremen and, for instance, for Thuringia (TH) (see Figure 1 in the main text), other states do not exhibit such an obvious trend. In the analysis in the first part of this Supplement, we, therefore, still allow for a general time trend but do not impose such a trend for each federal state. In contrast, as a next step we approach the problem differently by allowing at the same time the analysis of whether the potential effect of the integration of doctor's offices into Germany's vaccination campaign differs between federal states.

$$s_{i,t} = \alpha + \beta t + \rho D_{\text{April 5}} + \eta_i D_i \times D_{\text{April 5}} + \nu_i + \epsilon_{i,t}. \tag{5}$$

In Equation (5), $s_{i,t}$ is explained by a time trend t, the variable $D_{\text{April 5}}$ that takes the value 1 for the period after April 5, 2021, and 0 otherwise as well as a federal state specific fixed effect v_i. A federal state dummy D_i is interacted with $D_{\text{April 5}}$ to investigate whether a change in $s_{i,t}$

[28] This follows from $\frac{\partial s_{i,t}}{\partial t} = \beta + \gamma_i D_i$ based on Equation (4).

potentially triggered by the integration of doctor's offices into the vaccination campaign differs between federal states. This approach enables an investigation of whether the integration of doctor's offices into the vaccination campaign potentially improved efficiency of the vaccination campaign on average and whether this effects differs between federal states at the same time. The interaction term $D_i \times D_{\text{April 5}}$ is defined such that the results of each federal state have to be interpreted relative to Bremen. The results of the regression are presented in Table 10.

	(1)	
$D_{\text{April 5}}$	0.245***	(8.81)
$D_{\text{April 5}} \times$ BB	-0.204***	(-2.24e+14)
$D_{\text{April 5}} \times$ BE	-0.180***	(-4.11e+14)
$D_{\text{April 5}} \times$ BW	-0.0912***	(-2.23e+14)
$D_{\text{April 5}} \times$ BY	-0.177***	(-4.21e+14)
$D_{\text{April 5}} \times$ HE	-0.121***	(-2.11e+14)
$D_{\text{April 5}} \times$ HH	-0.160***	(-1.80e+14)
$D_{\text{April 5}} \times$ MV	-0.135***	(-3.16e+14)
$D_{\text{April 5}} \times$ NI	-0.0668***	(-1.56e+14)
$D_{\text{April 5}} \times$ NW	0.0165***	(2.63e+13)
$D_{\text{April 5}} \times$ RP	-0.185***	(-2.65e+14)
$D_{\text{April 5}} \times$ SH	-0.180***	(-2.17e+14)
$D_{\text{April 5}} \times$ SL	-0.196***	(-2.80e+14)
$D_{\text{April 5}} \times$ SN	-0.136***	(-2.90e+14)
$D_{\text{April 5}} \times$ ST	-0.108***	(-2.04e+14)
$D_{\text{April 5}} \times$ TH	-0.146***	(-2.64e+14)
$Time\ trend$	0.000848	(0.31)
Constant	0.334***	(14.14)
Observations	320	
R^2	0.395	
R^2 adjusted	0.328	

t statistics in parentheses

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 10: Output table for Equation (5).

One can see that the coefficient of the dummy $D_{\text{April 5}}$ is significant at the 0.1%-level. The coefficient of 0.245 reported in Table 10 implies that, all else equal, in the period after April 5,

24.5% *more* out of 100 available doses in a given week were vaccinated on average, or, in other words, 24.5% less doses were held back as reserves in Bremen. In interpreting the results, the potential effect of the integration of doctor's offices into the vaccination campaign is a jump in $s_{i,t}$ by 24.5% for Bremen. That jump is lower for all other federal states except for Northrhine-Westphalia, where the jump is $0.245+0.0165 = 0.2615$. The lowest increase occurs in Saarland where the apparent effect of the integration of doctor's offices into the vaccination campaign is $0.245 - 0.196 = 0.049$.

A more detailed discussion on the differences between Regressions (4) and (5) is appropriate. The main difference is that (4) allows the time trend to vary between federal states whereas (5) allows the effect of the dummy $D_{\text{April 5}}$ to be federal state-specific. In contrast to (4), in (5) all differences in the time dimension between federal states is absorbed by the interaction term $D_i \times D_{\text{April 5}}$ so that the time trend eventually becomes insignificant. Based on a graphical analysis of Figure 1 in the main text one cannot clearly state which approach is more appropriate. For instance, Lower-Saxony (NI) and Hesse (HE) show similar patterns after April 5, however, Lower-Saxony shows a clearer time trend. This indicates that Equation (4) appears to be a more suitable approach to identify differences in the time dimension between federal states. On the other hand, comparing Bremen and Lower-Saxony, one can see that Bremen has a more pronounced effect of $D_{\text{April 5}}$. One could argue that there is a more visible structural break in Bremen than in Lower-Saxony. In that case, Equation (5) seems more appropriate to identify differences in the time dimension. Based on these observations, it seems appropriate to discuss both variations. In any case, both estimations indicate structural breaks after April 5, so that the results presented here confirm the findings outlined in the main text.

Finally, it can be analyzed which federal states show a time trend and for whom a structural break after April 5 can be diagnosed. In doing so, we estimate the following regression for each federal state:

$$s_{i,t} = \alpha_i + \beta_i t + \rho_i D_{\text{April 5}} + \gamma_i D_{\text{April 5}} \times t. \tag{6}$$

In Equation (6), we test whether each federal state has a time trend, a structural break after April 5 and whether the time trend changes after April 5. The results are presented in Table 11.

federal state	time trend (t)	structural break ($D_{\text{April 5}}$)	Interaction ($D_{\text{April 5}} \times t$)
HB	none	positive***	negative**
BB	none	positive**	negative*
BE	none	positive***	negative***
BW	none	positive***	none
BY	none	positive*	none
HE	none	none	none
HH	none	positive*	none
MV	negative***	none	positive**
NI	none	none	none
NW	none	positive***	none
RP	none	none	none
SH	none	none	none
SL	none	none	none
SN	none	positive***	negative***
ST	none	positive***	negative**
TH	positive**	positive***	negative***

Table 11: Time trend and structural break after April 5, 2021, and the interaction between the time trend and the structural break in $s_{i,t}$ for each federal state. The number of stars indicates the p-values of the respective t-statistics. In contrast to the previous analyses, *** indicates the $p \leq 0.01$, ** $p \leq 0.05$ and * $p \leq 0.1$.

Table 11 shows that 10 out of 16 federal states exhibit a structural break after April 5, 2021. That structural break is positive, i.e., an upward jump in $s_{i,t}$ is observed. However, starting from that higher level, one can see that in 6 of these federal states (HB, BB, BE, SN, ST, TH) the shares $s_{i,t}$ start to decline again, which follows from the negative sign of the coefficient γ_i of the interaction term $D_{\text{April 5}} \times t$. This indicates that in these federal states there was a strong initial impetus on $s_{i,t}$ at the beginning of April 5, which began to level out afterwards.

In the remaining 4 federal states (BW, BY, HH, NW) the shares remain at a higher level. For Mecklenburg Western Pomerania (MV), we do not find a structural break, however, a negative time trend is found with an opposing positive trend after April 5 (positive coefficient of the interaction term). No effect of the integration of doctor's offices into the vaccination campaign is found for 5 federal states (HE, NI, RP, SH, SL).

As a further robustness check, we have performed the Zivot-Andrews structural break test, (*21*). This can be seen a conservative approach because the test identifies endogenously at most one structural break. The test identifies a structural break in calender weeks 13 and 14 (i.e., the weeks around April 5) in 6 federal states (including, in particular, Bremen and Northrhine-Westphalia) despite the scarcity of observations. These findings are consistent with the interpretation outlined in the main text that the effect we identify is driven by those federal states where the integration of doctor's into the vaccination campaign had a particularly strong effect.

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Supplementary materials

Supplementary Text: Supplements 2-4