

# **The impact of vaccine lotteries on COVID-19 vaccination rates: Evidence from Poland**

Bachelor Thesis

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# 1 Introduction

In March 2020, the world came to a sudden stop due to the spread of COVID-19. Governments took drastic and unprecedented steps to slow the spread of the virus: Shops were shut down, schools and universities were closed and millions of workers had to work from their home office or kitchen desk. Many of these measures to counteract COVID-19 had negative side effects: They destroyed billions of dollars of wealth, led to unemployment and strangled the mental health of many. Most importantly however, apart from all measures to stop its spread, the COVID-19 pandemic itself cost the lives of millions of people around the world.

Just a year after the first COVID-19 cases appeared in China, the first vaccines against COVID-19 were approved. With them came the hope of a return to normality and a severe reduction of the death toll of the pandemic. At the beginning of the worldwide vaccination effort, the producers of the vaccines were clearly not able to meet the world demand at the necessary speed and scale. Therefore, a shortage of vaccines lead to rationing: Vaccines were only provided to the most vulnerable groups of the population, such as healthcare workers or the elderly. When vaccines became widely available, policymakers however had to learn that a considerable share of people were hesitant or unwilling to receive the shot. Globally, the COVID-19 vaccine was one of the most relevant and hotly contested topics of 2021, demonstrated by Google Trends<sup>1</sup>, which places the COVID vaccine as the 3rd most searched news story of the entire year.

The problem of vaccine hesitancy led governments to think in new<sup>2</sup> ways again. From beer to bratwurst and fishing license to lotteries: Many different incentives were introduced on national and local levels, in order to persuade people of the COVID-19 vaccine. Lotteries might be especially interesting, since they include an element of uncertainty. A vaccine lottery, in the context of this thesis, refers to a lottery with cash or non-cash prizes, in which vaccinated people could participate at no additional cost, thereby acting as a possible reward for vaccination. Policymakers hoped that this would persuade additional people to get vaccinated, increasing the total vaccination rate of the population.

This thesis will investigate the impact of such lotteries. It therefore tries to answer the question: What are the effects of vaccine lotteries on the share of the population vaccinated against COVID-19? The empirical analysis using a vaccine lottery in

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<sup>1</sup>see <https://trends.google.de/trends/yis/2021/GLOBAL/>

<sup>2</sup>As we will see, the idea of incentives and lotteries in public health is not entirely new.

Poland finds no evidence for a significant increase in the share of the population fully vaccinated against COVID-19. It however suggests that it might have incentivized some people who would have gotten vaccinated anyway to do this earlier, to take advantage of the lottery, thereby temporarily increasing the vaccination rate by around 6 percentage points.

As we will see in section 2.1, there is already a large literature on COVID-19 vaccine lotteries, especially in North America. So far, there has however been no study evaluating the Polish vaccine lottery in detail. This thesis therefore adds a new case study to the existing literature.

In order to spur the slow-moving national vaccination campaign, the Polish government announced the lottery on May 25, 2021<sup>3</sup>. It was open from July 1, 2021 until September 30, 2021. The main prize of the lottery was a cash prize of one million PLN, but it also included smaller cash and non-cash prizes and a lottery-like incentive scheme for municipalities. The empirical analysis was conducted using the synthetic control method based on Abadie and Gardeazabal (2003), a popular method for comparative case studies. Out of a donor pool of 6 other Eastern European countries and using additional predictor variables, a synthetic control unit (“Synthetic Poland”) was constructed to evaluate the (causal) effect of the policy. Daily data on vaccination rates, published by the respective governments/government agencies and prepared by Our World in Data and additional data from Eurostat and the Wellcome Global Monitor were exploited for the analysis.

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<sup>3</sup>This was around five months after the authorisation of the first COVID-19 vaccines in the EU and the subsequent start of the Polish vaccination campaign.

## 2 Background

### 2.1 Literature review

#### Incentives in public health

Governments are facing public health challenges at every corner. But how can they motivate people to live healthier lives? Behavioural economics can offer several ways to influence the decisions of individuals, probably the least severe form are nudges.

Nudging is a concept mainly brought to the public through the work of Thaler and Sunstein (2008). They define a nudge as an intervention that “alters people’s behavior in a predictable way without forbidding any options or significantly changing their economic incentives” (p. 6). Nudging can be applied in various ways, it is however often connected to lifestyle topics, such as nutrition and diet. For example, in an experiment in Denmark (Friis et al., 2017), the aim was to promote the consumption of vegetables in the setting of a self-serving buffet, which included salad and other dishes in large bowls. As a nudge, the food environment was changed by arranging green plants and herbs around the food bowls. In a second experiment, salad was pre-portioned into smaller take-away bowls. The results showed that the intake of energy from vegetables of the participants can be increased by pre-portioning the salad. Although many studies evaluating the impact of nudges find positive effects of the respective interventions, these results should be interpreted with caution, since a lot of studies, including Friis et al. (2017), were conducted in the lab and may therefore not be reproducible in a real-world setting (Ledderer et al., 2020).

Besides nudging, policymakers could try to change economic incentives. Governments have been using taxation as a means of influencing the behaviour of individuals for a long time, for example in alcohol and tobacco policy. Both in developed and developing country, it has been shown that raising prices leads to reduced consumption of tobacco (Yeh et al., 2017; Immurana et al., 2021).

Beyond taxation, policymakers could also use other financial incentives to motivate changes of individual behaviour to tackle public health challenges, such as (small) cash payments or lotteries. There have been many studies evaluating such possible schemes, typically using randomised control trials. Several meta-analyses found that such incentives can be successful in inducing behaviour changes. For example, Giles et al. (2014) evaluated 16 studies on issues such as smoking cessation, health screenings, physical activity and vaccinations. The authors found that financial

incentives are more effective than no intervention at encouraging healthy behaviour. This finding is also confirmed by Mantzari et al. (2015), who evaluated 34 studies and additionally concluded that this effect is stronger for the most deprived individuals, thereby possibly reducing health inequalities.

There is also some literature on lotteries as an incentive in public health, apart from COVID-19 vaccine policy. Björkman Nyqvist et al. (2018) find that the introduction of a lottery program reduced HIV incidence in Lesotho. Lotteries can also successfully increase cycling and walking activity (Ciccone et al., 2021; Patel et al., 2018) and participation in chlamydia screenings (Niza et al., 2014).

## **Incentives to increase COVID-19 vaccination rates**

In march 2020, when the COVID-19 pandemic struck the world, it was not foreseeable that vaccines would be available in just about nine months. When they were available and hailed as the possible end of the pandemic, it may not have been clear that rolling out vaccines was so difficult. In countries around the world, there was a considerable amount of vaccine hesitancy. Dealing with this hesitancy has led policymakers and researchers to thinking about how to increase vaccination rates, by means of vaccination mandates and passports, nudges, cash and non-cash prizes and lotteries.

A very widely used tool, especially in Europe and the US, were vaccination passports. The access to social gatherings/places (e.g. restaurants, bars, clubs, stadiums), international travel and quarantine regulations were subject to vaccination against COVID-19. Besides ethical concerns, for example potential disqualification of minorities from social life because of a historically higher distrust in government (Gostin et al., 2021), the evidence on the effectiveness of such regulations is mixed. A synthetic control analysis of six countries found that COVID passports were successful in increasing daily vaccinations in countries with lower than average vaccination rates. In more average countries (Germany and Denmark), such regulations were less successful (Mills & Rüttenauer, 2022). These cross-country comparisons should however be treated with caution, since there are large variations across countries when it comes to the extent of the use of COVID passports. While a comparison of Poland (very restricted use of COVID passport) and Lithuania (wide use of COVID passport) suggests a positive effect of passports on vaccination rates (Walkowiak et al., 2021), it has to be noted that COVID passport may also have negative effects on vaccine uptake, since frustration about reduced autonomy might lower willingness to get vaccinated (Porat et al., 2021).

Besides the carrot-and-stick approach, governments have also used smaller nudges



and financial incentives, such as cash payments and non-cash rewards to increase COVID-19 vaccination rates. Probably the most influential study to date on cash payments and nudges was carried out in Sweden (Campos-Mercade et al., 2021). Using a randomised control trial, the authors find that even “small” cash payments of around 24 US dollars can significantly increase vaccination rates, while small nudges could not increase vaccination rates. While some studies also suggest a measurable positive effect of cash payments on vaccination rates (Wong et al., 2022; Klüver et al., 2021; H. Kim and Rao, 2021), there is also evidence against this effect. In another study, the results indicated that neither behavioural nudges (text messages) nor cash payments could increase vaccination rates among the hesitant citizens (Jacobson et al., 2022). Sprengholz et al. (2021) also find that cash incentives do not increase the willingness to be vaccinated.

There is also a vast literature specifically on COVID-19 vaccine lotteries, also evaluating real-world lotteries. Dubé et al. (2022) analyse the effectiveness of a vaccine lottery in Québec (Canada) and find a relatively small impact on vaccination rates. A survey in Australia found that the vaccine lottery there was successful in increasing willingness to be vaccinated (Jun & Scott, 2022). The majority of studies on COVID-19 vaccine lotteries however dealt with lotteries in US states. Studies on vaccine lotteries in Louisiana and Massachusetts found different effects. Whereas the lottery in Louisiana increased vaccine uptake (Wang et al., 2023), a vaccine lottery in Massachusetts did not significantly increase vaccination rates although prizes were higher (Y. Kim et al., 2023). There are also several papers investigating multiple state COVID-19 lotteries at once. All of these papers find that most, but not all of the lottery programs were successful in increasing vaccine uptake (Robertson et al., 2021; Acharya and Dhakal, 2021; Fuller et al., 2022).

A specific focus can be observed with respect to Ohio. There is a quite large number of studies evaluating the “Ohio Vax-A-Million” lottery, which was the first COVID-19 vaccine lottery in the US. In total, a majority of the reviewed literature casts a positive light on the efficacy of the lottery. While Mallow et al. (2022) find a positive effect of the lottery on vaccination rates, another study cannot support this view (Walkey et al., 2021). There have also been four studies evaluating the lottery using the SCM. These studies construct a synthetic Ohio out of a donor pool of other US states. Three of these studies find small positive effects of the lottery of vaccine uptake (Brehm et al., 2022; Barber and West, 2022; Sehgal, 2021) and one does not find a robust effect (Lang et al., 2022).

So far, there has been one study dealing with the vaccine lottery analysed in this

thesis. Kuznetsova et al. (2022) shortly evaluate different vaccine incentives across Europe, including the Polish policy. By applying an interrupted time series analysis based on an ARIMA approach, the authors suggest a slight positive effect of this lottery. There has however not been a study dealing in detail with the Polish lottery yet.

## 2.2 Institutional background

The COVID-19 policies in Poland (especially with respect to vaccines) can be considered as relatively “relaxed”. Poland did not widely use the EU COVID passport with respect to social life (citation here). Instead, it was only used for travelling/entry into the country. The Polish vaccination campaign started on December 27, 2020 with the vaccination of a nurse (citation for total vaccination campaign). Until September 2021 when two vaccines were no longer used, all of the vaccines approved by the EU (AstraZeneca, Pfizer/BioNTech, Moderna and Johnson & Johnson) were used for vaccinations. Citizens who wanted to get vaccinated had to register and select their preferred vaccine prior to the vaccination. In May 2021, the waiting time between the first and the second dose (Johnson & Johnson required only one dose) was set at five weeks. In the first weeks and months of the vaccination campaign, vaccines were only available for health care workers and senior citizens. By the start of May 2021 however, vaccines were widely available (cite here), but not enough citizens were willing to get jabbed. In a relatively short time, Poland therefore moved from a problem of scarcity to the problem of vaccination hesitancy.

In general, vaccination rates in Poland have been low compared to some western European countries, including neighbour Germany. In the context of eastern Europe, vaccination rates have however not been exceptionally low. Many eastern European countries experienced relatively low vaccination rates and a hesitancy to get vaccinated within their respective population. In the media, a general distrust into the government and a lack of educational campaigns (“Poland’s vaccine scepticism – A European problem,” 2021) and a chaotic and conflicting communication by the government (Wanat, 2021) have been cited as potential reasons of the low vaccine uptake in Poland. Many other eastern European countries also refrained from a large-scale use of COVID passports and the carrot-and-stick approach in general. Therefore, to increase vaccination rates, the only remaining options are campaigns/nudges and providing incentives. This has actually been implemented in several ways, e.g. Slovakia and Bulgaria also adopted lotteries at some point and

Lithuania (?) provided cash incentives.

Table 2.1: Prizes of Polish vaccine lottery

	Cash prizes	Non-cash prizes
Instant	13,000 * 500 PLN 39,000 * 200 PLN	-
Weekly	60 * 50,000 PLN	720 electric scooters
Monthly	6 * 100,000 PLN	6 small vehicles
Main	2 * 1,000,000 PLN	6 middle class vehicles

Source: Service of the Republic of Poland

The empirical analysis will be based on a vaccine lottery implemented in Poland from July 1, 2021 to September 30, 2021. It was announced on May 25, 2021 (Charlish & Florkiewicz, 2021). The policy had two main elements: A lottery for all adult fully vaccinated people (two doses) in Poland (of the Republic of Poland, 2021b) and a lottery-like monetary incentive scheme for municipalities (of the Republic of Poland, 2021a). The main prize of the lottery was a cash prize of 2 \* one million zloty<sup>4</sup>, but it also included smaller monthly, weekly and daily cash prizes and non-cash prizes (cars and electric scooters) with a total volume of 140 million zloty, as depicted in table 2.1. Citizens were able to enter the lottery both online and by phone. It was organized by the state-owned polish lottery company *Totalizator Sportowy*, which also operates other popular lotteries in Poland.

Poland's lottery can be seen as a mixture of different brands of lotteries. Especially in the US, state governments have focused on lotteries with high rewards and relatively low winning probabilities (e.g. Ohio, Massachusetts with prizes of one million USD). A completely different concept would be the use of relatively low prizes (e.g. below 1000 USD) with relatively high winning probabilities (citation/example here). The Polish policy included both relatively small prizes (instant prizes) but also quite large prizes (main/final draw), thereby combining the best of both worlds.

As part of the monetary incentive scheme for municipalities, the municipality with the highest percentage of the vaccinated in the country received two million zloty. Three other municipalities who had the highest percentage of the vaccinated

<sup>4</sup>At the time of announcement on 25/05/2021, this was equal to around 220,000€, with an exchange rate of around 0.22 PLN to EUR

in their comparison group<sup>5</sup> received one million zloty each. The 500 quickest other municipalities reaching a vaccination rate of 67% won 100.000 zloty each.

One obvious question with respect to the synthetic control is the time of intervention. Although the actual lottery started on July 1, we will choose the time of announcement as the point of intervention, since the time of being fully vaccinated is not relevant for the entry into the lottery. If the lottery has an effect, we will expect it to be observable from the time of announcement. On the other hand, if we were to set the intervention time at July 1, we might have the problem of a so-called anticipation effect, impacting the credibility of the synthetic control negatively. This will be further discussed in chapter 3.1. As a robustness check for the result we obtain, we will however also estimate a synthetic control using July 1 as the time of intervention.

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<sup>5</sup>There were three groups: Municipalities with a population of up to 30,000, cities with a population of 30,000 - 100,000 and large cities with a population above 100,000.

## 3 Method and data

### 3.1 Synthetic control method

The synthetic control method is a relatively new method in causal inference. It was first established by Abadie and Gardeazabal (2003) in order to investigate the economic effects of terrorism in the basque country and further developed by Abadie et al. (2010). Abadie (2021) is a summary of these prior developments as well as the requirements and inference methods and can be regarded as the basis of this section.

Synthetic control methodology has been applied widely in economics, but also in other (social) sciences such as political science. Its specific case of application are comparative case studies, where a specific case, e.g. a policy or intervention of any form are compared to another case, for example without a similar policy (?). One idea in the context of comparative case studies is difference-in-difference. It might be straightforward to use matching to find the closest/most similar unit to the treated unit and take this as a control, allowing to estimate the average treatment effect of the policy by simply taking the difference (citation for matching). Finding a single unit which matches well might however in many cases be difficult, especially when making cross-country comparisons. The synthetic control method comes into play here and extends the difference-in-difference method. The very basic idea is to create a synthetic control unit as a combination of multiple control countries, to then estimate the average treatment effect (ATE) of the policy/intervention. For instance, it has been used to evaluate the effects of European integration (Campos et al., 2019) or the effect of natural disasters on economic growth (Cavallo et al., 2013), by constructing synthetic control countries without European integration or natural disasters.

#### Requirements

There are some important requirements that need to be fulfilled, in order to obtain a valid and interpretable synthetic control. These have been outlined in detail by Abadie (2021) along with the formal definition and the inference. The first one is that the evaluated policy/intervention has a sufficiently large effect. When the effect of an intervention is too small, it may not be possible to distinguish this effect from other shocks to the outcome variable. Additionally, the volatility of the outcome variable should not be too high, to prevent over-fitting.

The second one is that there exists a suitable comparison/control group. Countries that are also subject to similar interventions or other shocks to the outcome variable in the given time frame should be excluded from the donor pool. What this means for the analysis in this thesis is outlined in section 3.1. Furthermore, we should try to select countries that are not too different from the treated country for the donor pool, to prevent interpolation bias (cite or write about interpolation bias).

Another important requirement is that there is no anticipation effect, so that citizens do not anticipate the enactment of a policy. If there were an anticipation, we would expect our synthetic control to become biased and not useful for estimating the causal effect of the treatment. This should however not be expected as a problem in the Polish lottery application, since there is no possible reason for anticipation (there were no prior lotteries in Europe and no rumors about the lottery before the announcement (check again)). This will be picked up again in chapter 4, as a robustness check of the obtained synthetic control.

Next, it is crucial that we do not have any spillover effects on untreated units. If this were the case, the lottery in Poland would have effects on vaccination rates of donor pool countries. This requirement should however be fulfilled in this application, there is at least no possible theoretical argument for such a relationship.

In terms of data, it is important that we have enough pre-intervention values of the outcome variable, so that the synthetic control can approximate these values well. A larger number of pre-intervention outcomes reduces the bias of the synthetic control, making it more valid (sounds weird).

The fulfillment of these assumptions/requirements will be further discussed in section 5.

## Formal definition

What we observe is some outcome variable  $Y_{jt}$  for  $J + 1$  units from  $t = 1$  to  $T$ . The first unit ( $j = 1$ ) is the treated unit for  $t > T_0$  while all other units are untreated units. The intervention (in this analysis the announcement of the lottery) occurs at  $T_0 + 1$ , meaning that there are  $T_0$  pre-intervention time periods. We also observe  $k$  predictors, which include the pre-intervention observations of the outcome variable  $(Y_{j1}, Y_{j2}, \dots, Y_{jT_0})$  and additional time invariant unit level characteristics  $\mathbf{Z}_j$  (covariates, as outlined in section 3.2). These  $k$  total predictors can be summarised by the vectors  $\mathbf{X}_j = (Y_{j1}, Y_{j2}, \dots, Y_{jT_0}, \mathbf{Z}_j)'$  for units  $j = 1, \dots, J + 1$ . It therefore follows that the  $(k \times J)$  matrix  $\mathbf{X}_0 = (\mathbf{X}_2, \mathbf{X}_3, \dots, \mathbf{X}_{J+1})$  captures all the predictors

of the untreated units<sup>6</sup>.

The average treatment effect (causal effect) is defined as the difference between the potential outcome of the treated unit with intervention, which can be defined as  $Y_{1t}^I$ , and its potential outcome without the intervention,  $Y_{1t}^N$ :

$$\tau_{1t} = Y_{1t}^I - Y_{1t}^N \text{ for } t > T_0 \quad (3.1)$$

By definition, the outcome with intervention is known and the outcome without intervention is hypothetical for  $t > T_0$  for the treated unit. Therefore, to estimate the causal effect, it is sufficient to estimate  $Y_{1t}^N$ . How can this problem be solved?

The first straightforward idea might be to use a difference-and-difference with matching approach and choose the closest unit  $j^*$ , the so-called best single control (Doudchenko & Imbens, 2016), which solves:

$$j^* = \arg \min_{j > 1} \|\mathbf{X}_j - \mathbf{X}_1\| \quad (3.2)$$

Taking a difference then results in an estimator for the average treatment effect:

$$\hat{\tau}_{1t} = Y_{1t}^I - Y_{j^*t} \quad (3.3)$$

Using a single control approach however does not seem like a desirable estimation technique. Firstly, in many cases (including the Polish lottery) a single control does not achieve a good pre-treatment fit, especially when cross-unit differences are relatively large. Secondly, a difference in difference approach requires the parallel trend assumption, which is very hard to justify. Parallel trend requires that in the absence of treatment, the difference between treatment and control group is constant over time (possibly cite here). In the application of the Polish vaccine lottery, this would mean that the difference in the vaccination rates of Poland and country  $j^*$ , the closest unit pre-intervention, would be constant if there were no lottery. This does not seem realistic, since there are many different factors influencing vaccination rates in each country, thereby making changes in the difference relatively likely.

The synthetic control method developed by Abadie and Gardeazabal (2003) proposes to use a weighted average of donor pool units as a synthetic control, thereby

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$${}^6\mathbf{X}_0 = \begin{bmatrix} Y_{21} & Y_{31} & \dots & Y_{J+11} \\ Y_{22} & Y_{32} & \dots & Y_{J+12} \\ \vdots & \vdots & \ddots & \vdots \\ Y_{2T_0} & Y_{3T_0} & \dots & Y_{J+1T_0} \\ \mathbf{Z}'_2 & \mathbf{Z}'_3 & \dots & \mathbf{Z}'_{J+1} \end{bmatrix}$$

not experiencing the problems of a single control estimation (Synthetic control does not require parallel trend assumption). The synthetic control and the following estimator for the average treatment effect are therefore defined as:

$$\hat{Y}_{1t}^N = \sum_{j=2}^{J+1} w_j Y_{jt} \quad (3.4)$$

$$\hat{\tau}_{1t} = Y_{1t}^I - \hat{Y}_{1t}^N \quad (3.5)$$

The weights  $\mathbf{W} = (w_2, w_3, \dots, w_{J+1})'$  are chosen, such that the synthetic control matches as closely as possible the pre-intervention path of the predictors of the outcome variable for the treated unit (possibly cite). Therefore the weights have to be chosen so that they minimize this difference. The optimal weights  $\mathbf{W}^* = (w_2^*, w_3^*, \dots, w_{J+1}^*)'$  solve:

$$\mathbf{W}^* = \arg \min_{\mathbf{w}: w_j \in [0,1], \sum_{j=2}^{J+1} w_j = 1} ||\mathbf{X}_0 \mathbf{W} - \mathbf{X}_1|| \quad (3.6)$$

(Potentially include factor model) This is subject to the weights being non-negative and summing up to one, an important assumption in the classic SCM. This assumption can be relaxed to allow for non-negative weights, in this thesis we will however keep it. We can therefore simply plug in these weights to obtain the estimated average treatment effect from (3.5):

$$\hat{\tau}_{1t} = Y_{1t}^I - \sum_{j=2}^{J+1} w_j^* Y_{jt} \quad \text{for } t > T_0 \quad (3.7)$$

## Inference

Based on Abadie et al. (2010), the most common way of inference in synthetic control is using permutation through the use of placebo effects. A synthetic control unit is constructed for all the untreated countries in the control group, as if there was a treatment for these countries. If the magnitude of the effect for the actually treated unit is extreme compared to the placebo effects, the effect can be regarded as significant. In order to do this analysis, the gaps between the synthetic control and the actual outcome can be plotted for all selected countries, in order to visually compare the size of the effects. One possible problem of this concept might be that it could possibly be difficult to obtain a good pre-treatment fit for all units in the donor pool, especially with a relatively small donor pool. Additionally, this way of



constructing inference is in some sense “blurry”, since it does not rely on quantitative measure.

A possibility of quantification is a test statistic which measures the ratio of the post-intervention fit relative to the pre-intervention fit (possibly cite 2010 abadie here). The root mean squared prediction error of the synthetic control is then defined as:

$$R_j(t_1, t_2) = \left( \frac{1}{t_2 - t_1 + 1} \sum_{t=t_1}^{t_2} (Y_{jt} - \hat{Y}_{jt}^N)^2 \right)^{\frac{1}{2}} \quad (3.8)$$

From there it is possible to compute  $r_j$ , which measures the quality of the fit in the post-intervention period compared to pre-intervention and is given by the ratio of the post-intervention RMSPE and pre-intervention RMSPE:

$$r_j = \frac{R_j(T_0 + 1, T)}{R_j(1, T_0)} \quad (3.9)$$

It is then possible to compute a p-value for the permuted test:

$$p = \frac{1}{J + 1} \sum_{j=1}^{J+1} I_+(r_j - r_1) \quad (3.10)$$

where  $I_+(\cdot)$  is an indicator function that returns one for non-negative arguments and zero otherwise.

## Extensions

One possible extension, proposed by Doudchenko and Imbens (2016), is to allow for the weights of the synthetic control to be negative.

Several extensions to the classic SCM (outlined so far) have been proposed in the last years. Ben-Michael et al. (2021) have proposed an augmented synthetic control based on ridge regression, a regression technique which produces better results under multicollinearity (when predictor variables are correlated with each other). The augmented synthetic control is aimed at applications in which a sufficiently good pre-treatment fit cannot be achieved and a reduction of the following bias is desired.

## 3.2 Data

First, we will estimate an RDD model to estimate the effect of the lottery on COVID-19 cases in Poland, similar to the analysis by Kuznetsova et al. (2022). For this, time

series data on COVID-19 cases by “Our world in data” will be utilized.

In the main synthetic control analysis, the impact of the policy on the vaccination rates will be investigated. Data for the outcome variable ( $Y_{jt}$ ) vaccination rate (both one vaccination and fully vaccinated) is taken from a data set created by Our World in Data (Mathieu et al., 2021). This very large data set is a collection of vaccination rates and other vaccination statistics from all countries of the world, coming directly from the respective government/government agency and summarized by Our World in Data. If the data is provided by the governments, it can give us a daily time-series of vaccination rates for every country of the world.

One of the most important aspects in the application of SCM is the choice of the donor pool. As outlined in 3.1, the treated country should not be an outlier compared to the control countries. It is therefore sensible to select countries that are similar to Poland, both in general and with respect to vaccination rates. Therefore, twelve central/eastern European countries with sufficient data availability (AT, BG, CZ, EE, GR, LV, LT, HR, HU, RO, SI, SK) are initial candidates for the donor pool. From this list, several countries are dropped who experienced similar interventions or shocks to the vaccination rate in the given time frame. Greece (cash incentive of 150€ for young people), Czechia (holiday incentive), Austria (need to find a reason here), Lithuania (cash incentive + other incentives), Romania (cash and lottery incentive). Estonia, Czechia and Slovenia implemented some small incentive schemes for doctors<sup>7</sup> and state employees<sup>8</sup>, these are however not considered as a big enough shock to vaccination rates and Estonia, Czechia and Slovenia will not be dropped. Croatia and Hungary are removed because of too many missing values, since a sensible trend can not be constructed using interpolation. Slovakia (nochmal checken) only reported weekly values, a reasonable interpolation was however possible. The donor pool then consists of six countries: Bulgaria, Czechia, Estonia, Latvia, Slovakia and Slovenia.

There are however missing values for several countries. Sometimes these missing values follow a specific pattern (e.g. Poland: values are missing on Sundays) while there is no specific pattern for some other countries. Linear interpolation is used to replace the missing values, by drawing a straight line between the two adjacent data points (citation here). Other imputation techniques such as spline interpolation<sup>9</sup> were also considered. A last observation carried forward (LOCF) or a mean imputation do not make any sense in the setting of a vaccination rate, which is an increasing

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<sup>7</sup>Doctors were offered a cash incentive for a specific number of vaccinations

<sup>8</sup>Additional holiday

<sup>9</sup>Spline interpolation estimates missing values such that the curvature of the time series is minimized (need citation here).

function. The differences between linear and spline interpolation are relatively minor in this specific application.

Table 3.1: Predictors of selected countries

	Poland	Synthetic Poland	Mean donor
GDP per capita <sup>a</sup>	12,810	15,642.287	14,428.333
Influenza vaccination rate <sup>b</sup>	0.104	0.133	0.139
Population density <sup>c</sup>	123.600	87.871	79.667
Share with tertiary education <sup>d</sup>	0.289	0.283	0.286
Share of elderly <sup>d</sup>	0.182	0.185	0.198
Trust in science <sup>e</sup>	0.872	0.895	0.891

<sup>a</sup> in USD, 2020 (Eurostat)

<sup>b</sup> among elderly (over 64), 2019 (Eurostat)

<sup>c</sup> in persons per km<sup>2</sup>, 2019 (Eurostat)

<sup>d</sup> over 64 years, 2020 (Eurostat)

<sup>e</sup> 15 to 64 years, 2020 (Eurostat)

<sup>f</sup> 2020 (Wellcome Global Monitor)

In order to find the best fit for the weights, additional predictors ( $\mathbf{Z}_j$ ) are used. The choice of these variables is potentially very important in determining the optimal weights of the synthetic control unit, as seen in section 3.1. GDP per capita, the share of elderly (over 65), the share of people (15-64) with tertiary education, population density and the year of entry into the EU all adjust for general country specific differences, but partly also for differences in vaccine uptake. Income, age, education and the proximity to the nearest vaccination center (it is assumed that countries with higher population density have - on average - a closer proximity to vaccination centers) are all relevant determinants of COVID-19 vaccine uptake (Viswanath et al., 2021; need to check + possibly additional citation). The share of elderly vaccinated against Influenza and trust in science are possibly also important indicators of “vaccine openness”. We would expect countries with higher Influenza vaccination rates (before the spread of COVID-19) also to have higher COVID-19 vaccination rates, since the population might generally be more open to the basic idea of vaccinations and that there might be a more sophisticated culture of health prevention (too unspecific). A similar reasoning applies to trust in science. When citizens generally place more confidence in scientists, they would also be more likely to be open to the idea of vaccinations.

Ideally, the use of a “political variable” would have been a good idea, since differences in vaccine uptake exist across party preferences. This problem might be the most well-known in the US (Ruiz & Bell, 2021), but it is also believed to

Table 3.2: Composition of synthetic Poland

Country	Weight
Bulgaria	0.001
Czechia	-
Estonia	-
Latvia	0.269
Slovenia	0.248
Slovakia	0.482

be a relevant predictor of vaccine hesitancy (even before COVID-19) in Europe (Schernhammer et al., 2022; Kennedy, 2019). When using other European countries as a donor pool, it is however very difficult to compare political beliefs across countries, mainly because of the large differences in party ideologies across countries. One idea would be to use the vote share for parties along the groups in the European Parliament, there are however several problems with that. Firstly, there are relatively large differences between parties within certain groups<sup>10</sup> and secondly, elections and surveys are very volatile in many European countries compared to e.g. some US states (if left, need citations).

Another possible predictor which was considered is trust in government. The data on this is also available from the Wellcome Global Monitor. It is ultimately however not selected, for several reasons. Firstly, trust in government is often highly volatile. For example, if a very unpopular government is replaced by a new government, this might increase the trust into public sector dramatically in a very short time span. The problem of a comparably high volatility should be especially pronounced in a time of crisis like the COVID-19 pandemic, where temporarily very high/very low infection rates can lead to quick changes in public opinion. While there also exist deep-rooted cross-country differences in trust in government (e.g. possibly higher distrust in former soviet influenced countries compared to western countries (possibly need citation here)), the presence of the described volatility means that the variable trust in government will not be used.

The data analysis has been carried out in R using the *synth* and *SCtools* packages, generating synthetic Poland. Table 3.1 shows descriptive statistics of the predictors of Poland, synthetic Poland and the donor pool mean of the predictors. Table 3.2 presents the composition of synthetic Poland for the analysis of the share of fully

<sup>10</sup>For example, the Renew Europe group in the EP consists of liberal parties in a very broad sense, including both left-wing liberal parties and liberal-conservative parties.

vaccinated citizens with the respective unit weights. The data and R scripts can be found in the corresponding GitHub repository ↗<sup>11</sup>.

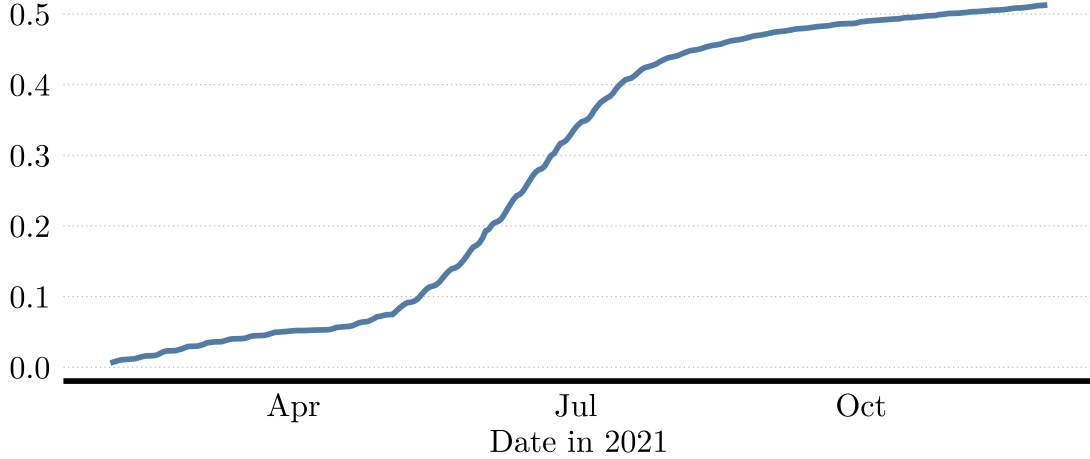
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<sup>11</sup>See appendix for further information

## 4 Results

First of all, let us look at vaccination rates in Poland from a descriptive point of view. Figure 4.1 plots the vaccination rate (fully vaccinated) in Poland in 2021.

Figure 4.1: Share of population fully vaccinated in Poland (in %)

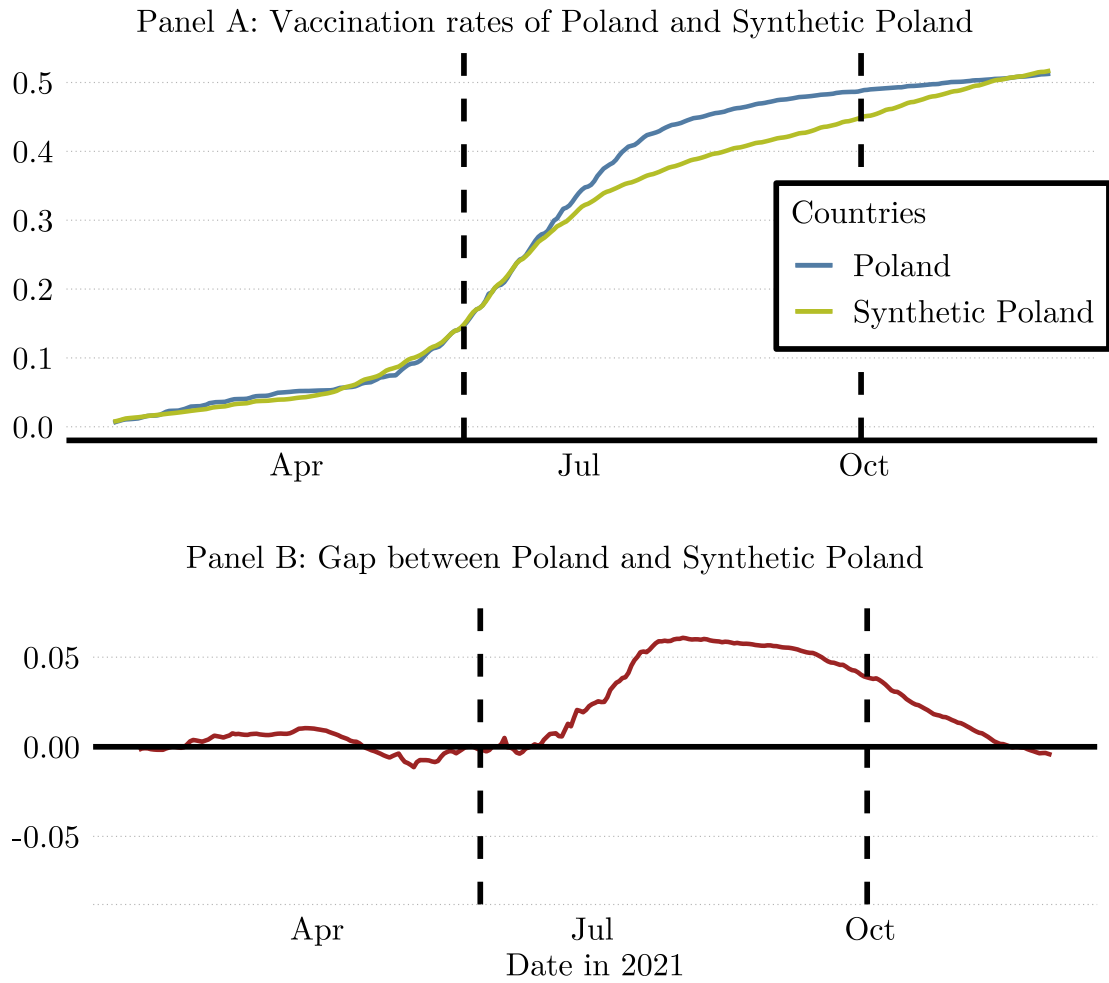


As other countries, Poland first dealt with a shortage of vaccines, leading to necessary rationing, having to favor older and chronically ill citizens first. Towards the summer, this shortage significantly loosened its grip. Although the growth rate in the vaccination rate increased significantly, for countries like Poland with a comparably high vaccine hesitancy, the problem turned from a vaccine shortage to a shortage of people willing to get vaccinated. Simply from looking at figure 4.1, we can not observe a sharp or outstanding change in the growth rate at the time of announcement or shortly after<sup>12</sup>. This is however also not expected, since the magnitude of the effect of lotteries on vaccination rates is generally not very large, as outlined in section 2.1.

We therefore applied the synthetic control method, as described in section 3.2. Figure 4.2 plots the vaccination rate (fully vaccinated) for both Poland and synthetic Poland. We observe a solid, but not perfect pre-treatment fit (too unspecific). After a short lag after the intervention (as expected), we can see a slow decoupling between Poland and its synthetic control. This difference continues increase to around 5 percentage points. As time progresses, the gap however tends to decrease again, and by the end of November (after the end of the lottery), the vaccination rates

<sup>12</sup>We would expect that it takes several weeks for any significant change to be visible, since getting fully vaccinated takes/took around six to eight weeks

Figure 4.2: Synthetic control for the share of fully vaccinated in Poland



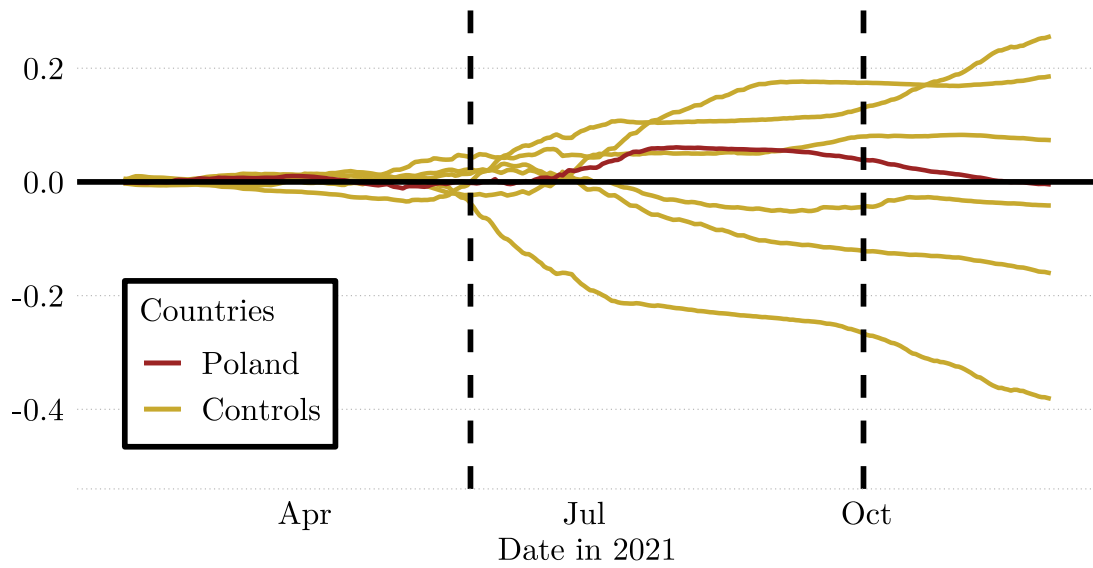
The two dashed lines refer to the announcement (25/05) and the end (30/09) of the lottery.

of Poland and synthetic Poland are back to the same level. Simply based on the plot, one interpretation could be that the lottery successfully induces some people who would have gotten vaccinated anyway to do this earlier, to take advantage of the incentive provided by the government. It however also suggests that the vaccine lottery was not particularly effective in reaching new people. It has to be noted that the more time has passed since the intervention, the synthetic control becomes more unreliable, as the prediction intervals in figure ... show. Therefore, the development in October and November should be interpreted with caution, but at first glance, it seems like the lottery was not successful in getting more people vaccinated, but only in getting people vaccinated earlier.

Employing the permutation based inference techniques discussed in section 4.1

also confirms the finding of no significant effect. Figure ... presents the placebo study. As can be seen, the magnitude of the effect of Poland is not comparably high and does not stand out in any way. Actually, the effect of Poland is the least extreme of all of the selected units. This finding also confirmed quantitatively. Using the discussed test procedure, a  $p$ -value of 0.7143 is obtained. Therefore, the hypothesis that the lottery had no effect in increasing vaccination rates cannot be rejected.

Figure 4.3: Placebo plot: Poland and control countries



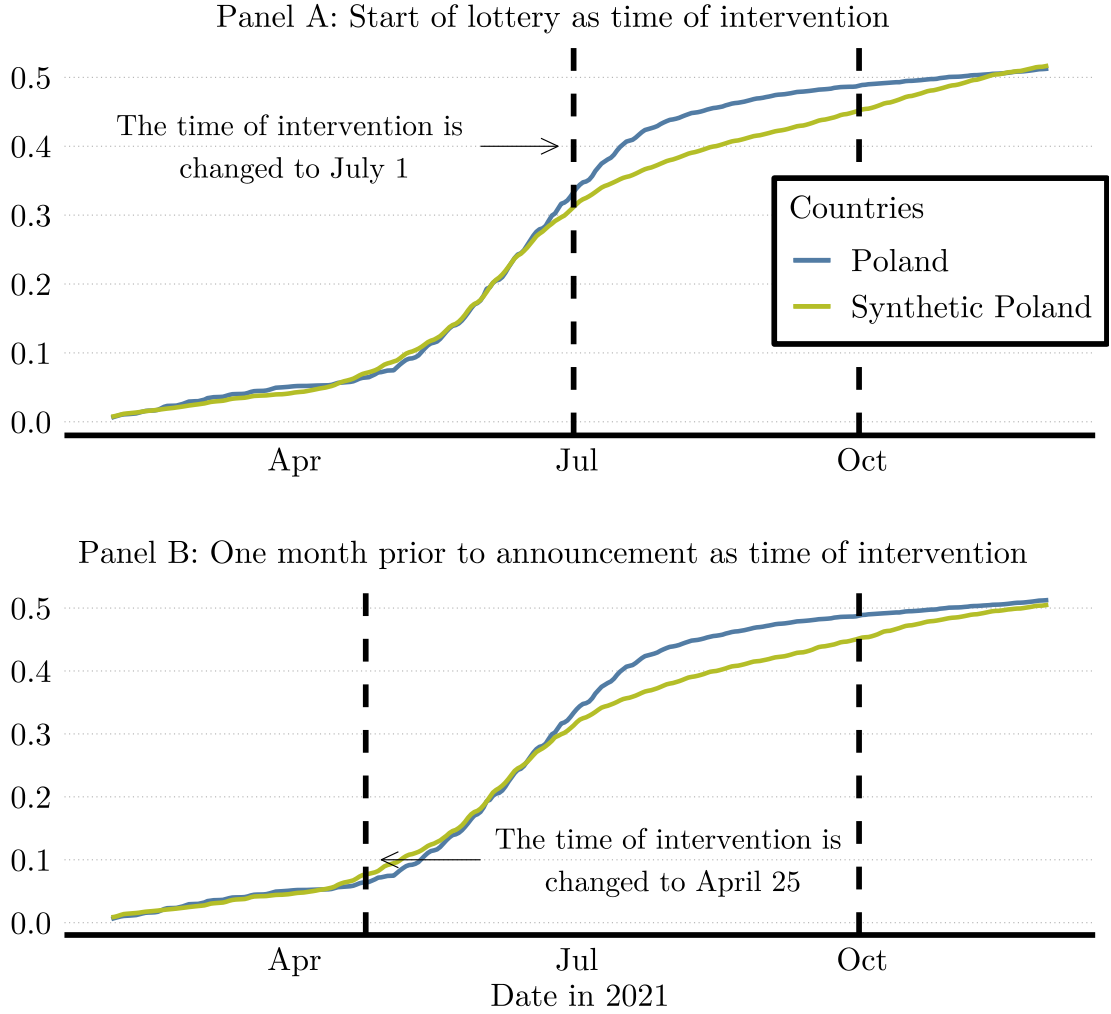
The figure shows the gaps between the actual and synthetic units for Poland as well as all of the control units. The synthetic controls of the control units are placebos (constructed as if there was a treatment).

## Robustness checks

Next, we will assess the robustness of our synthetic control. One option is to change the time of the intervention. As discussed earlier, there are two possible intervention points: The announcement and the start of the lottery, with the announcement being the more sensible option. In order to see how robust our synthetic control is, we will now use July 1, the start of the lottery as the intervention point. As can be seen from the upper panel of figure 4.4, changing the time of intervention from 25/05/2021 to 01/07/2021 has no visible effect on the synthetic control, with only very minor changes in the chosen weights. Importantly, the lag after the announcement of the lottery is clearly visible with both of these setups, with no lag after July 1.



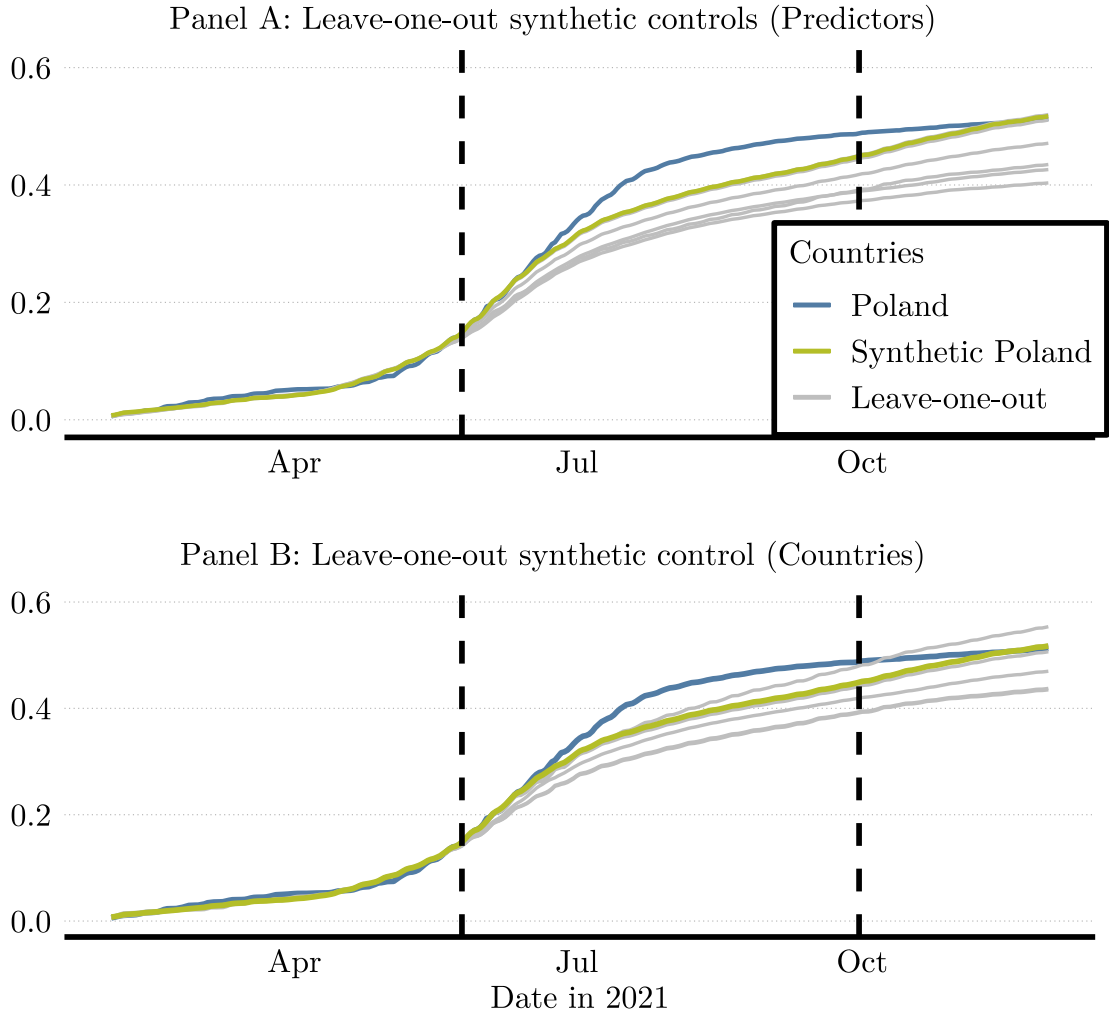
Figure 4.4: Poland and synthetic Poland with different intervention times



Another way of changing the time of intervention is backdating, meaning that the synthetic control is estimated using an arbitrary earlier intervention time. If the synthetic control is robust, we expect no drastic changes from the baseline result in figure 4.1. We therefore construct a new synthetic control, with a “fictional” intervention time one month earlier (April 25) than the actual investigation time. As observable in the lower panel of figure 4.4, the changes are also not too large, with the new synthetic control still tracking the path of actual Poland until the actual intervention occurs relatively well. We therefore conclude that this synthetic control is indeed robust to changes to the time of intervention. This finding also confirms that we do not suffer from an anticipation effect.

Another possible robustness check is to leave out certain predictors or countries.

Figure 4.5: Leave-one-out synthetic controls of Poland



With a relatively low number of predictors and donor pool countries, the effects of such a robustness check could potentially be larger in this setting. Figure 4.5 presents the result of a leave-one-out analysis of synthetic Poland, leaving out all of the predictors once, while keeping the others in, with the same with donor pool countries (solving the constrained minimization with only five countries). The synthetic control is not very robust with respect to the predictors, with three predictors being especially important to the robustness of the synthetic control, while the three other predictors only take on a minor weight and therefore are not as important to the robustness of the synthetic control. The same can be said with respect to the countries, where 3 countries received 3 larger weights in the original synthetic control. Therefore, leaving one out of these three countries also has a relatively large effect. Overall, the

result is not surprising, since only a total of 6 predictors and 6 donor pool countries are used and the differences in the vaccination rates across donor pool countries are not to be underestimated.

The results of this analysis are also in line with a synthetic control analysis of the effect of the lottery on the vaccination rate in terms of the first dose only, showing no signs of a significant effect of the lottery, with a  $p$ -value of xxxx. More details on this analysis can be found in the appendix.

## 5 Discussion

What is the impact of vaccine lotteries on vaccination rates? The results of the analysis do not suggest a significant effect of the lottery on vaccination rates. One interpretation of the graph could be the fact that people who would have gotten vaccinated anyways decided to do this earlier to take advantage of the lottery.

Applying the synthetic control method in comparative case studies offers many advantages (Abadie, 2021). Firstly the fit of the synthetic control is very transparent. A graph of the actual unit and its synthetic control and a table such as table 3.1, which presents the predictors of actual and synthetic Poland clearly show the differences between the two units, allowing for a straightforward evaluation of whether the use of a synthetic control is appropriate in this application. Transparency is also an advantage with respect to the composition of the synthetic control unit. A clear list of the different weights provides the opportunity to assess the fulfillment of some of the requirements of the synthetic control, e.g. the spillover effect. For example, the problem of a possible spillover effect could be disregarded, when the country this might apply to has a weight of 0 or very close to 0. Another advantage might be that only pre-intervention outcomes are used to construct the synthetic control unit. This means that it might<sup>13</sup> prevent researchers from changing the specifications of the synthetic control, for example donor pool countries or covariates, to achieve a certain result (e.g. a significant result ( $p$ -Hacking)), after initially constructing it.

Besides these advantages, the synthetic control method itself also has some disadvantages and weaknesses (Bouttell et al., 2018). One advantage is that there is a lack of quantitative criteria for crucial requirements. As we have seen in section 3.1, the similarity of donor pool countries is a relevant criterion for a valid synthetic control, there is however no definition of what exactly means similarity. It is not uncommon that assumptions are hard to justify (e.g. instrumental variable approach (more specific)), but the argument of similarity can be made in many directions. Another possible problem in this respect is the judgement of the quality of the fit. There is no objective or quantitative measure to evaluate the pre-treatment fit of a synthetic control, meaning that the evaluation is always subject to a possible bias of the researcher.

There are several limitations of this application of the synthetic control method, making the estimated causal effect less valid.

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<sup>13</sup>It is of course still possible to compare the results of different specifications and select the specification which is "preferred".

Firstly, the number of donor pool countries is relatively low. Therefore the number of combinations is obviously more limited compared to e.g. Ohio, where all other US States (minus states that experienced similar policies) can be selected for the donor pool. Similarly, in the analysis of Ohio’s lottery, other (neighbouring) states are very similar to Ohio, both in general and with respect to vaccination rates. Although the donor pool countries in this thesis are not too different compared to Poland<sup>14</sup>, cross-country differences are still larger than cross-state differences. Therefore the fit which is obtained from the constrained minimization is not perfect, albeit also not particularly bad.

Secondly, a vaccine lottery might be too little of an intervention to be relevant for a synthetic control. After all, the effect on vaccination rates that has been estimated for similar lotteries is often relatively low (e.g. Barber and West (2022): 1.5%). Poland’s lottery offers more prizes, but a lower main prize than some lotteries in North America. It might therefore be conceivable that the effect of the given policy in Poland is too small for a causal synthetic control analysis, since the effect of the intervention is not distinguishable from other relatively small shocks to the vaccination rate (e.g. some public figure speaking out against vaccination).

Another possible limitation of this analysis are the imputed values. As explained in section 3.2, some countries in the donor pool had a lot of missing values, most importantly Slovakia, which only reported weekly values and takes up the largest weight of Synthetic Poland. Although the graphs resulting from the linear interpolation look reasonable, this might still have a negative effect on the credibility of the presented synthetic control, as such differences can cause changes in the chosen weights of the synthetic control.

There are however also requirements of the synthetic control which this application should clearly fulfill. Firstly, we do not observe a sign of an anticipation effect, as seen in chapter 4. Secondly, the possibility of spillover effects: We do not observe any spillover effects of this lottery. Since we removed countries who adopted similar incentive policies, no country in the donor pool has adopted such a policy with Poland as a role model. Additionally, since we have shown that the lottery did not strongly increase vaccination rates in Poland, we also do not expect a general positive example of Poland in terms of an increased vaccination rate on other Eastern European countries. Lastly, the number of pre-intervention outcomes does not represent as problem. We start the optimization on February 1, 2021 and end it one day before the announcement, on May 24, 2021. Since daily data is used, we therefore have a

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<sup>14</sup>See table 3.1 for a comparison between Poland and the average of the donor pool

total of 113 (?) pre-intervention values of the outcome variable, therefore meaning that a solid fit of the synthetic control can be obtained.

To summarize, it is therefore important to note that the causal interpretation of the given results should be done with caution, because of these outlined limitations. This specific application is however also not particularly bad and not one of the worst applications of the synthetic control method (change sentence). Lastly it has to be noted that this thesis presents only one case study. While the results do not suggest a significant effect of the lottery on the vaccination rate, the applicability of these results on (at first glance) comparable policies is limited, mainly because of differences in the design of lotteries and very large differences in initial vaccination rates and other country specific predictors. One should therefore not make an evaluation of vaccine lotteries based on one specific case study, but rather using the breadth of the literature, which has been outlined in section 2.1.

## 6 Conclusion

The COVID-19 pandemic has brought innovative policies into action. Among them, vaccine lotteries.

As we have seen, nudging and the use of economic incentives can be successful in inducing changes in individual health behaviour, for example by increasing physical activities. Lotteries and other incentives may have also contributed to increasing vaccination rates in the COVID-19 pandemic, for example in Ohio, whose vaccine lottery has been evaluated several times.

In order to empirically assess the impact of vaccine lotteries on vaccination rates in this thesis, we examine a vaccine lottery implemented in Poland, from July 1, 2021 to September 30, 2021. The lottery consisted of cash and non-cash prizes of around 140 million PLN. To estimate the effect of this program on vaccination rates, the synthetic control method was selected. A synthetic Poland was constructed out of a donor pool of six other Eastern European countries.

The main results show no signs of a statistically significant increase ( $p$ -value: 0.7143) in the vaccination rate compared to the hypothetical scenario without the lottery on the long-term. It can however be observed that vaccination rates increase in the short-run, thereby possibly suggesting that people who would have gotten vaccinated anyways, may have chosen to do this earlier, as a result of the lottery.

At the time of writing, there has been no study dealing in detail with this specific policy in Poland. This thesis therefore adds a new case study to the vast literature on COVID-19 vaccine lotteries, which has so far focused on such policies in the US.

Are vaccine lotteries worth it? As discussed, the evidence on the effectiveness is mixed. When keeping in mind the costs of such a policy, it might even be a better idea to provide incentives at the local level, on a smaller scale. Possibly, a beer without a flaw, is better than a random draw, bratwurst and other snacks, outclass the “idiot tax”, a license for fishing, trumps a month of wishing.

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# Appendix

GitHub repository: [https://github.com/benediktstelter/bachelor\\_thesis](https://github.com/benediktstelter/bachelor_thesis)

All of the data of the covariates and the R scripts used to analyse the data can be found in folder "scripts\_data", along with some additional information in README.

# Affidavit

I affirm that this Bachelor thesis was written by myself without any unauthorised third-party support. All used references and resources are clearly indicated. All quotes and citations are properly referenced. This thesis was never presented in the past in the same or similar form to any examination board.

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Benedikt Stelter