UNIVERSITY OF GOTHENBURG

Thesis Title:

Quasi experimental study of SMS text messages as a nudging strategy for Covid-19 vaccination in Sweden

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“A little kinder than necessary in every aspect of daily life.
Then, everything becomes much more reasonable and meaningful.”

Wut Hmon

Abbreviations

DiD : Difference-in-Differences

FE : Fixed Effect

RE : Random Effect

SMS : Short Message Service

WHO : World Health Organization

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ABSTRACT

Introduction

In the roll-out of the COVID-19 vaccination program, a variety of policy tools were used to increase vaccination rates in Sweden. A SMS nudge intervention was implemented to increase vaccine adoption in Värmland and Västra Götaland among residents aged 16–39, 12 weeks after those aged >18 became eligible for vaccination in those counties.

Aim

The purpose of this paper is to assess the effect of SMS nudge interventions on COVID-19 vaccination uptake in Sweden.

Method

To analyze the adoption of the COVID-19 vaccine, quasi-experimental evidence and differences-in-difference methodologies were utilized. The period of interest is from week 26 to week 44 of 2021 (6 weeks after the SMS reminder). The targeted age group was divided into three strata for in-depth evaluation. The robustness of the model was examined by incorporating county-specific covariates and analyzing multiple timeframes.

Results

The estimated effect of the SMS nudge on COVID-19 vaccination uptake was a 0.0083 percentage point decrease in vaccination rates, with very wide confidence interval (95% CI -0.06; +0.05) 30-39-year-olds demonstrate a small positive impact in the treated group with a value of 0.005, while 16-17 and 18-29-year-olds are estimated at -0.04 and -0.01 units, respectively.

Conclusion

This thesis finds no evidence that SMS nudging has increased vaccination rates for COVID-19 in Sweden. Thus, instead of SMS, policy makers could consider utilizing other nudges. This result contradicts with previous studies, most likely because of the time lapse between the eligibility contact and SMS nudge implementation.

Keywords: SMS text nudge, Difference-in-differences, COVID-19 vaccination in Sweden

Abstract word counts: 244 words

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1. Introduction

1.1 COVID-19: Pandemic Disease in Sweden

In late December 2019, a coronavirus was discovered in a collection of individuals with respiratory distress syndrome in Wuhan, China. According to Chinese reports, the virus was spread through direct or indirect contact with workers at a seafood market in Wuhan. Then, in addition to the USA, it spread throughout China, Asia, Italy, Spain, and other countries in Europe (Umakanthan et al., 2020). As a result of globalization, coronaviruses quickly spread in places and nations where traveling abroad is common and convenient (Troiano & Nardi, 2021) (Umakanthan et al., 2020). On January 30, 2020, the World Health Organization declared the novel coronavirus a public health emergency. And on March 11, 2022, it declared the worldwide outbreak to be known as the COVID-19 pandemic (World Health Organization, 2020). The evidence from the data provided indicates that the COVID-19 disease was causing not only short-term but also long-term unfavorable health effects in many organ systems as well as mental health (Leung et al., 2020). This is consistent with other coronavirus diseases of a similar nature.

According to a 2022 WHO report (World Health Organization, 2020), 6.8 million individuals and more were reported dead from the COVID-19 sickness globally. Countries prioritized immunizing their population with the COVID-19 vaccine, which was initially introduced in late 2020, to protect individuals from the risk of infection with COVID-19. The WHO has developed a dashboard where each country's data may be seen, allowing for prompt reporting of COVID immunization, cases, and deaths (World Health Organization, 2021).

As of December 31, 2022, 2.68 million confirmed COVID-19-positive cases had been reported in Sweden. Out of these 2.68 million cases, 22,306 of them resulted in disease-related deaths (World Meters, 2021) and (World Health Organization, 2021). Sweden had a higher incidence rate across all age categories and a higher mortality rate up until August 2020, before the vaccine was launched, according to a COVID policy analysis study of Nordic countries (Yarmol-Matusiak, Cipriano, & Stranges, 2021). That has been attributed to inadequate nursing home care, ambiguous voluntary restraint measures, and ineffective contact tracing. However, in the later stages of the pandemic, Sweden made improvements in its testing capabilities, intensive care unit, and information dissemination. (Yarmol-Matusiak et al., 2021).

1.2 COVID-19 vaccination in Sweden

The primary objective of any vaccination is to mitigate the incidence of the disease as well as its associated morbidity and mortality, as stated by Dai et al (Dai et al., 2021). Similar to other vaccination initiatives, the COVID-19 vaccine is safeguarding the community against severe ailments and mitigating the strain on healthcare resources. The development of the COVID-19 vaccination was accomplished within a timeframe of less than a year since the onset of the pandemic. To ensure equitable distribution of available vaccines, collaborative efforts were being undertaken by GAVI (the Vaccine Alliance), WHO, and other regional agencies. Achieving a sufficient level of immunization across the global population is necessary to mitigate the risk of new cases and prevent further transmission of the disease (Polack et al., 2020). Covid 19 vaccination lasted up to 3 months only with 95% efficacy for >16 years old therefore, getting top up doses was important as well (Polack et al., 2020). The administration of COVID-19 vaccinations in Sweden commenced during Week 50 of 2020, following a national plan that involves a four-phase roll-out. The prioritization was based on age and risk factors (Wood, Pate, & Schulman). According to Swedish Health Agency (Folkhalsomyndigheten, 2020), the four phases were listed below in *Table 1*.

Table 1: Prioritization strategies of COVID-19 vaccination in Sweden

Phase 1	>80 years old staying in long term care or under home care service
Phase 2	65-79 years old, home caregivers and >18 years old under LSS act and other chronic underlying disease LSS act: Persons with intellectual and long-term physical disabilities and people with autism or conditions like autism
Phase 3	50-64 years old
Phase 4	18-49 years old

Swedish Public Health Agency was taking the leading role for COVID-19 vaccination programme of the nation and operationalizing the national plan was in the hands of 21 counties. Every county ensured that the COVID-19 vaccination initiative within their jurisdiction was in accordance with the national plan of the Swedish Public Health Agency. Consequently, various counties implemented diverse strategies to facilitate the administration of vaccinations to their residents, ultimately attaining national vaccination goals. Similar to other Scandinavian nations, the Swedish Folkhälsomyndigheten has refrained from mandating measures but has instead recommended that citizens receive the COVID-19 vaccination as a means of safeguarding themselves and others (Yarmol-Matusiak et al., 2021). Consequently, it was the responsibility of counties to undertake similar measures that did not involve law enforcement but rather aimed to promote a positive attitude towards COVID-19 vaccination among residents.

At the end of 2022, a significant proportion of the adult population in Sweden, specifically 84%, had been administered a minimum of two doses of the COVID-19 vaccine. Additionally, 65% of the population had received three doses of the vaccine. The vaccination rates in

Sweden are commensurate with those of other nations in the vicinity. In order to attain this objective, various counties have implemented diverse interventions aimed at promoting vaccination uptake among their residents. The perception of COVID-19 vaccination in Sweden is positively correlated with individuals' high educational attainment, high income, and trust in the government (Raffetti, Mondino, & Di Baldassarre, 2022). However, it remains unclear whether the aforementioned factors are also correlated with the decision to receive vaccination. It is the responsibility of the county to engage with low vaccine uptake groups and encourage them to receive vaccinations in order to attain higher levels of vaccine coverage nationwide.

1.3 Theoretical framework: Nudging in Public Health Policy of COVID-19 vaccine in Sweden

COVID-19 vaccine invention was the game changer to steadily putting the world back to normality from pandemic. Globally, the governments were trying to nudge the citizens to increase the optimal utility of available COVID-19 vaccination by incentivizing with cash/ non cash voucher, paper/ electronic reminders, lottery, travel fare, accompany fee, mobile vaccination station etc (Reñosa et al., 2021) (Jacobson, Chang, Shah, Pramanik, & Shah, 2022).

The fundamental character of “Nudge” must not limit or control one’s freedom of choice (Thaler, 2008). The main reasons of implementing nudge as an intervention are leading people towards to make better decision as people tend to make inconsistent decision. A nudge should also be simple, effective and low-cost techniques that encourage the adoption of new behaviours. Due to such reasons, nudges are used as an intervention in behavioural change programme in public health (Thaler, 2008). Counties in Sweden used different types of health promotion interventions to pursue the residents to get COVID-19 vaccination. Some of them were fall under the characteristic of nudge defined by Richard Thaler, including sending SMS text messages sent to residents.

Another concept mentioned by Richard Thaler is the choice architecture. Choice architecture is defined as presentations of the options in different ways which consequently effect the decision making of individual, society or organization. Therefore, those who develops that presentation is the choice architect. Many policy makers, businessmen, healthcare professionals supported the choice architecture concept and used them in designing behavioural change programme towards residents. Some tools were used designing default option, providing feedbacks, expecting errors mappings, structuring complex choices and incentives (Thaler, 2008). Nudges are framed with those tools by choice architects to ensure the choice options are arranged in a way that objectified the decision making process of people.

During COVID-19 time, many tools were used by health policy makers in terms of proposing restrictions, health promotions and vaccination programme. Some examples of effective choice architecture were (1) sending SMS that provided direct link for vaccine booking (Dai et al.,

2021) and first available timeslot was selected as a default (Patel, Milkman, et al., 2022). However, incentive nudges are as importance as non-incentive nudges while designing the nudges, depending on who the user is, who benefits and who profits (Thaler, 2008). On other hand, incentivised nudging are being criticised for ethical reason, in a way that the nudges were framed to make cash-driven decision instead of better behavioural aspect (Reñosa et al., 2021). Therefore, the public policy using nudge as a tool must be cautious in a way that are rationale and do maximize the freedom of choices. Nudging becomes part of the public health interventions and public policy in being able to reach the large scale of communities often implementing with low or high resources requirement (Patel, 2021).

By applying the nudge and choice architect concept, many countries including Sweden have used different vaccine nudge methods to reach to general or targeted people for COVID-19 vaccination. A Delphi Panel study has done for COVID-19 vaccine nudges across the world (Wood et al., 2021). It highlighted that the used nudge tools might be the same but efficacy of the implemented nudge might differ among the respondent groups (Wood et al., 2021) (Jacobson et al., 2022). "Not to miss any of the family members at important party/ events later, take care of yourself now" with images of weddings, graduations, occasions etc was aired on Swedish television, soon after vaccine rolled out in late 2020 (Wood et al., 2021). On average of 80% of the cohort in this Delphi Panel Study agreed and commented that it was portraying the fear, guilt, self-blaming for the loss and reactance (Wood et al., 2021). Therefore, the timing and portrayed massage of the nudge must be precise, harmless, and purposeful.

Counties have used their financial sources in costly interventions such as vaccine mobile van, drop-in centers, extra manpower with extra opening hours, home vaccination services for limited mobility population group, compensating travel fare etc. On the other hand, traditional, cheap and less time-consuming nudge options were used as well, such as sending SMS text messages, opening hotline for vaccine appointment, sending letters to the mailbox and announcing on existing counties' website or physical newsletters.

Löfgren and Nordblom have developed the theoretical framework of nudge-based decision making process and it gives the guidance to a situation where a nudge is likely to be effective (Löfgren & Nordblom, 2020), not in every situation. Their paper mentioned that, a nudge could only work when the choice was made without paying attention (Löfgren & Nordblom, 2020). At individual level, the choice to be made might not be important but in the society, the large benefit is expected in some cases. Therefore, policy makers are nudging individuals to take action for societal benefits (Löfgren & Nordblom, 2020). As an example, the SMS nudge intervention was initiated 18 weeks after the affected aged group were called in which the assumption was to pursue those inattentive residents to get vaccination in some of counties of Sweden (Värmland, 2021), (VGR, 2021). The initiation of SMS intervention was launched after realization of lower vaccine uptake in specific aged group as well. This agreed with the libertarian paternalism where the choice architectures create the choices which lead to pick the better decision for the society without forcing or limiting the options (Thaler, 2008).

The counties in Sweden are the choice architectures to create the reasonable nudges at the right time to make the better choice at their inattentiveness. Getting vaccination is an important decision for individual and for the societal perceptive. However, behavioural economics has shown that individuals do not always make rational decisions (Thaler, 2008). Thus, the policy makers, choice architectures, used the tools to contemplate the inhabitants who would make the inattentive choice of getting vaccinated in a large scale. Perhaps, the inhabitants with attentive choice of getting vaccinated might have done so at early stages. This theoretical framework is useful to evaluate the influence of nudges in COVID-19 vaccine programme in Sweden.

1.4 Previous literature on Nudges in public health

The pre-booked letter intervention, issued to Uppsala County's 16- and 17-year-old residents, has been assessed in Sweden (Bonander, Ekman, & Jakobsson, 2022). It concluded that the pre-booked letter-nudge intervention with this low-risk group had a positive impact on the COVID-19 vaccine rate. This is very similar to “Default option” of nudge mentioned by Thaler. Basically, the choice architectures defaulted and pre-selected the best option for the recipients among other available option. Thaler gave an example of “organ donation” where Donating organs due to sudden death as a default option under healthcare register. Countries like Austrua, Belgium, France, Sweden were using default as a strategy to have willing donors. In Denmarks, Netherlands and Germany, people are given choice to opt out/ opt in for organs donations.

Another randomized control trial study evaluating the cash incentive component as the nudge strategy was conducted in Sweden. The result showed that giving each COVID-19 vaccine recipient a cash incentive of 200 SEK increased vaccine uptake by 4.2 percentage points (P 0.05) (Campos-Mercade et al., 2021). Campos-Mercade also pointed out that the ethical perspective of the economically beneficial incentive may not inherently improve the behavior of individuals toward COVID-19 vaccination.

In the Northeastern United States, a randomized controlled trial (RCT) was carried out with an average age of 50 participants (Patel, Milkman, et al., 2022). To remind participants of their forthcoming primary care visits, including immunizations, 19 separate SMS text messages were sent 2-3 days before the appointment. The findings show that across all 19 distinct types of messages, the SMS text message intervention increased primary healthcare visits and immunizations by an average of 1.8 percentage points, or 6.1% (Patel, Milkman, et al., 2022). The results indicate that the SMS text message intervention led to a statistically significant increase in primary healthcare visits and vaccinations by 1.8 percentage points or 6.1% on average of all 19 different type of messages (Patel, Milkman, et al., 2022). t is still unclear, though, whether sending an SMS with the subject line "Covid vaccination specific" will lead to better results.

A different RCT was conducted in the Northeastern United States. The receivers of an SMS text message were urged to "get COVID-19 vaccinated within two weeks" (Patel, Fogel, et al., 2022). After the 2-week intervention period, the treatment group adhered to the policy 4.9% more frequently than the control group (Patel, Fogel, et al., 2022). After 4 weeks of follow-up, the vaccination trends of the two groups had returned to a similar tendency (Patel, Fogel, et al., 2022). In RCT scenario, summoning restricts the freedom of choice while still producing the desired results. Another US RCT found that sending an SMS reminder (highlighting ownership) after declaring vaccine eligibility improved COVID-19 vaccine uptake by 3.5 percent (Dai et al., 2021). According to Dai et al., SMS reminders were also sent to residents to remind them of an important occasion and to nudge individuals who were unsure about COVID-19 immunization.

1.5 SMS nudge in COVID-19 vaccination programme in Sweden

During the final week of 2020, Sweden initiated its COVID-19 vaccination program, which consisted of four distinct phases and was implemented across 21 counties. The distribution of vaccines was based on age and risk profiles. Following a year of implementation of the COVID-19 vaccination program in Sweden, approximately 48% of the populace has received at least one dose of the COVID-19 vaccine. The vaccine coverage across counties exhibited variability, with Stockholm and Värmlands reporting rates ranging from 46.5% to 51% across all age groups.

Please refer to *Figure 1* below. There might be multiple factors contributing to the variation in vaccine coverage across different counties. One potential explanation could be attributed to the nudges formulated by the choice architects, also known as policymakers, of the counties.

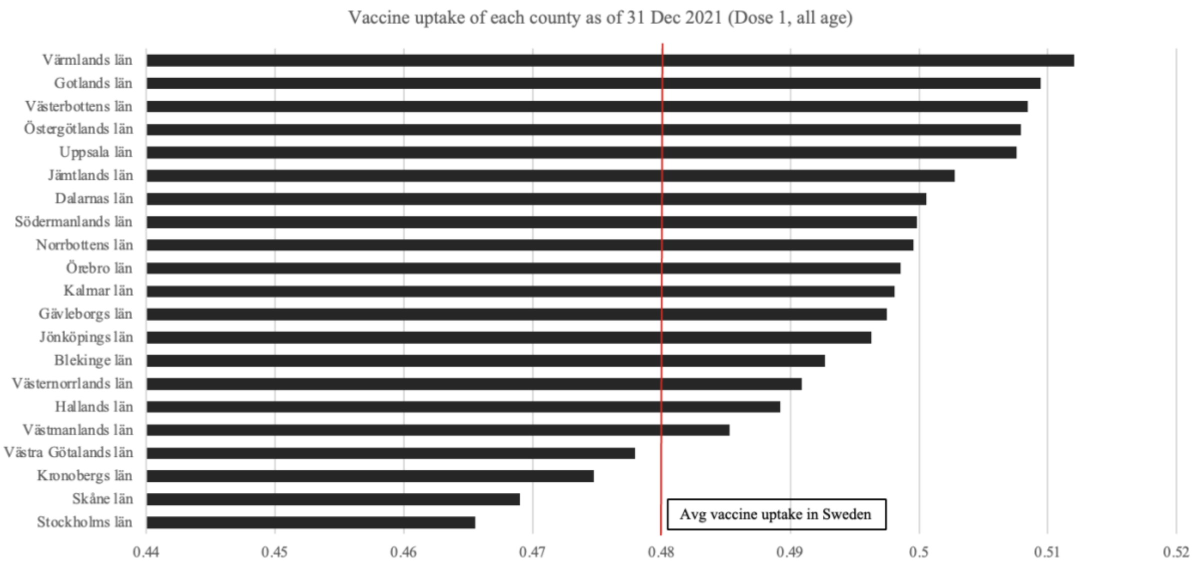

Figure 1 Vaccine uptake (%) of Sweden for all aged groups with at least one dose of COVID-19 vaccine (31 Dec 2021)

Although the Public Health Agency launched a general awareness campaign for COVID-19 vaccination, there were varying reactions from residents, both attentive and inattentive, towards the vaccination program. Various counties employed diverse visibility nudges, electronic and paper reminders, and pre-opted defaulting of the earliest time slot on their online booking system. These are the examples of nudges which are low cost, high level in freedom of choice and guiding to make better decision, defined (Thaler, 2008). On the other hand, the counties implemented expensive interventions such as mobile vaccination vans, drop-in centers, compensation for transportation expenses, and extended service hours.

In some counties of Sweden, SMS message were sent to the inhabitants to get COVID-19. the act of promoting vaccination through SMS messaging can be classified as a form of "nudge" (Thaler, 2008). When the summons is not embedded in the SMS message, it provides users with flexibility of choice. The utilization of SMS text messages has been widely implemented in this context by various counties, as well as in other healthcare and immunization practices (Reñosa et al., 2021).Yet not all the counties in Sweden have used this. However, it should be noted that not all Swedish counties have implemented this practice. The timing of sending SMS messages entails various factors that must be taken into account to optimize their effectiveness.

In Sweden, the counties can be classified into two groups with respect to SMS text nudges, (1) Counties those sent SMS text massage to inhabitants regardless of previous vaccine status as treatment group (2) Counties with No SMS intervention control group. In Sweden, two counties, Värmland and Vastra Goteland Region, used SMS nudge intervention which is mentioned more detailed in data collection session of this paper (VGR, 2021) (Värmland, 2021). In Week 38, the residents of two counties were notified via SMS, and both counties initiated the fourth phase of vaccination in Week 26. There was a 12-week interval between the launch of phase four and the implementation of the SMS nudge. Thus, it can be inferred that the SMS nudges dispatched by the two counties were intended to target inattentive decision-makers with regard to COVID-19 vaccination (Löfgren & Nordblom, 2020). hose individuals who paid attention were well informed, aware of the repercussions that would result from not receiving the COVID-19 vaccination, and responded promptly after hearing the eligibility call for their age groups (Löfgren & Nordblom, 2020).

1.6 Thesis rationale

Within the field of economics, it is commonly assumed that individuals act in a rational manner and make decisions that are advantageous for both themselves and society as a whole. However, the principles of behavioral economics suggest an alternative perspective (Thaler, 2008). Despite the fact that vaccination is the most advantageous option for individuals, there exists a degree of reluctance among certain individuals to receive the COVID-19 vaccine. It is possible that individuals may not have been adequately informed or faced ambiguous circumstances that hindered their decision to receive vaccination. Consequently, the counties employed the nudge theory as a means of encouraging individuals to obtain vaccination protection. The SMS nudge intervention in Varmland and VGR can be classified as a "mere nudge" according to the definition (Thaler, 2008). This sort of intervention was one of several that produced a positive behavioral shift toward COVID-19 immunization. Löfgren's decision-making process based on nudges has claimed that (1) a nudge would only work for an inattentive decision and (2) the nudge can be considered effective if the outcome of a decision is uncertain or if the decision is made based on intuition or heuristics (Löfgren & Nordblom, 2020). In this particular instance, two counties attempted to target individuals who were susceptible to nudges and uncertain about receiving vaccinations, or those who were at risk of creating barriers such as reprioritization or forgetfulness regarding the event. Thus, the aforementioned theoretical framework enables the examination of our research inquiry pertaining to the influence of SMS nudges on vaccination rates in Sweden.

"Nudge" interventions were implemented throughout Sweden, including the establishment of drop-in centers, the extension of service hours, and the Vaccine Week campaign, among others. The effects of nudge strategies may differ across various approaches. As a result of the various levels of cost involvement, whether targeted or broad population approach, comparing across nudges may result in a biased evaluation of the impacts. This paper focuses on the effects of SMS nudge intervention on COVID-19 vaccination rates in comparison to a control group that did not receive SMS nudges. It is also achievable within the designated timeframe of the thesis document. Another key theme of the paper pertains to the status of the initial dose of the COVID-19 vaccine. According to Reosa et al. (2021), people who have previously received doses of the same immunization regimen are more likely to adhere to subsequent doses, which may explain this phenomenon (Reñosa et al., 2021). In summary, the objective of this study is to examine the disparities in vaccine uptake between the control and treatment groups as a result of the SMS nudge intervention. Additionally, ascertain plausible factors that influence the residents' decision-making process regarding the acquisition of the COVID-19 vaccine.

Despite there are studies regarding SMS nudge, the author is not aware of any Swedish studies that have examined the effects of SMS nudge in health programs for behavioral change in a true empirical environment. This constitutes an additional rationale for substantiating the originality of the research.

2. Aim and Research question/s

The aim of the study is to analyse if SMS nudge intervention of Swedish counties affected COVID-19 vaccination uptake of the habitants. The research question of the paper is

- What was the impact of SMS nudge intervention on COVID-19 vaccination rate in Sweden?

3. Method

3.1 The SMS nudge intervention

Initially, the nudge exercises for each county were identified through the press releases pertaining to COVID-19 vaccination issued by the respective counties. All counties, except for Jönköping, have successfully archived the aforementioned information on their respective regional websites. Therefore, Jönköping was removed from the denominator and now nudges information from 20 counties were collected for this paper. Subsequently, data pertaining to nudges received from regional websites was compiled and organized using Microsoft Excel software, with the aim of generating weekly summaries for each county. The counties of Värmland and Vastra Gotaland utilized healthcare registries to distribute SMS messages, irrespective of the recipients' prior COVID-19 vaccination status. The SMS nudge intervention in VGR and Värmland counties was aimed at individuals within the age range of "16–49" years and "16–39" years, respectively. It was observed that a proportion of 25% of the total counties in Sweden, specifically 5 out of 20, have disseminated various types of SMS messages with the aim of encouraging COVID-19 vaccination. The utilization of SMS message intervention is perceived as a inexpensive approach that offers unrestricted autonomy to the recipients, thereby encouraging them to make positive decisions based on the "nudge" principle as proposed by Thaler (Thaler, 2008). Among the five counties under consideration, namely Stockholm, Gotland, and Uppsala, a targeted push SMS has been dispatched exclusively to individuals who have registered on either the "Always Open-Alltid öppet Mobile application" or "1177.se" subsequent to receiving their initial dose of the COVID-19 vaccine. Patel (2021) noted that individuals who have received the initial dose of the vaccine are more inclined to receive the subsequent dose without requiring any prompting (Patel, 2021). According to the decision-making theory, those who patiently waited for a COVID-19 booster vaccination are vigilant decision-makers, and their choice utility for the following dose is maximized (Löfgren & Nordblom, 2020). In addition, they have confidence in vaccination and are aware of the significance of the vaccine, resulting in a lower nudge-ability relative to COVID-19 vaccine virgins. Consequently, the study has excluded those three counties due to the fact that the push messages in those counties were sent to inhabitants with at least the first dose of the COVID-19 vaccine. On the other hand, the 15 counties that chose not to use SMS as a nudge intervention for COVID-19 vaccination are categorized as the "control" group. Please refer the *Appendix 1*. The figure illustrated in Figure 2 defines the division of the counties into distinct groups, namely the "control" and "treatment" groups.

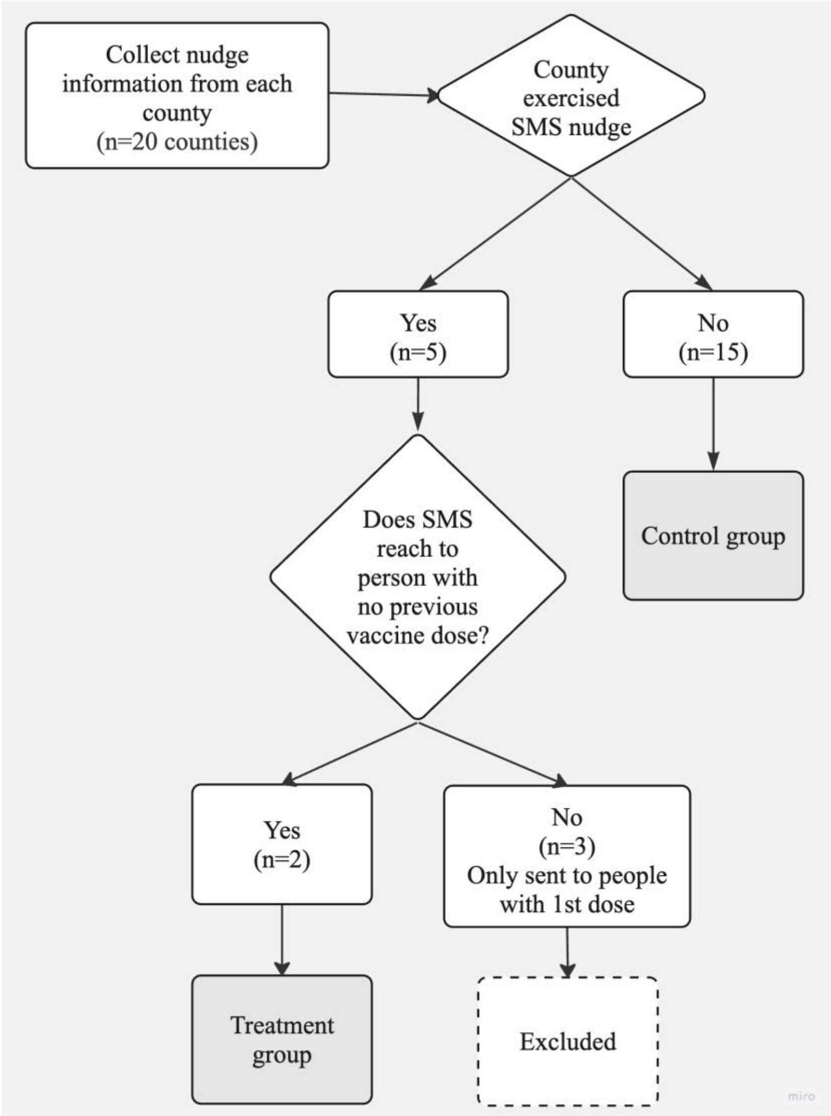

Figure 2 Flow diagram of grouping counties based on SMS nudge intervention.

During Week 26 of 2021, vaccinations were made available to residents over the age of 18 in both counties, VGR and Värmland. The implementation of the SMS nudge intervention took place in Week 38 of 2021 in both cases, as reported by the respective sources (VGR, 2021) and (Värmland, 2021). This study focused on the age range of individuals residing in two counties, specifically those between the ages of 16 and 39 who received SMS texts from the counties. According to Patel's randomized controlled trial (RCT) study, the duration of the impact of the SMS intervention ranges from four to six weeks, provided that additional SMS reminders are sent (Patel, Fogel, et al., 2022). On the basis of this, this article will assume that the effect of an SMS nudge lasts for up to six weeks after the SMS is delivered.

3.2 Data collection

The vaccination rates of the treatment and control groups before and after the SMS intervention are the study's primary outcome of interest. Weekly aggregate vaccination data by location, age group, and vaccine dose were collected from the Swedish Public Health Agency's vaccine registry from 2020 to 2022. The statistics on the outcomes were narrowed down to the 16–39-year-old age range that was targeted by the SMS program, and they cover the period up until the end of 2021. Three counties, namely Stockholm, Gotland, and Uppsala, have been excluded from the dataset. As previously stated, the county of Jönköping was dropped from the dataset as a result of lacking nudge-related information on the county's official website. The percentage of vaccine uptake has been calculated as number of vaccines administrated divided by population of the aged group of the county. The vaccine uptake data has been categorized based on vaccine status, specifically into groups that have received a minimum of one COVID-19 vaccine dose, two doses, three doses, and so on, within each age group. SMS messages were dispatched to individuals aged 16-39 years in two counties of the treatment group, irrespective of their prior COVID-19 vaccination status. This paper aims to assess the impact of SMS nudges on individuals who have received the first dose of the COVID-19 vaccine, based on logical reasoning and factual evidence.

The longitudinal panel data set was obtained, wherein vaccine uptake was recorded on a weekly basis for each county. Seventeen counties, comprising of 15 counties in the control group and 2 counties in the treatment group, have been monitoring the progress of vaccine uptake since the commencement of the vaccination program. Consequently, a total of 17 panel groups were established, each with a weekly schedule for monitoring the progress of vaccine administration. The total number of observations was 884, which is equal to 17 counties multiplied by 52 weeks in 2021.

3.3 Other variables and descriptive statistics

Other variables of each county, such as the proportion of males and females, the site of birth, the level of education, the level of income, the level of trust in healthcare services, and the degree of urbanization, were gathered in order to determine the relationship between SMS nudge treatment and these variables. These data were gathered from www.kolada.se and www.scb.se .

When making decisions on healthcare services, such as the COVID-19 vaccination, sex is the primary factor. The percentage contribution of males and females can be found in the statistics on Statistik data basen (the statistical data base of Sweden, SCB). The same source was also used to obtain demographic information about the place of birth, namely the percentage of Swedish and foreign-born people. Additionally, SCB data on the level of urbanization in each county was gathered. In Sweden, agglomeration is defined as the percentage of the population that lives in an urban area with a settlement of at least 200 people. 88% of people live in urban areas in Sweden (SCB, 2022).

Socioeconomic status variations in each county were collected based on the age range of interest. The level of education is important for making wise decisions. As per (Patel, Milkman, et al., 2022), the people with higher educational background show more adherence to the healthcare advice. Those with greater educational backgrounds adhere to medical recommendations more frequently. The mean income of the targeted age group (16–39 years) in each county has also been collected for this study design.

Trust to the government has shown positive impact on the healthcare utilization and adherence to the advice (Bonander et al., 2022) (Dai et al., 2021). Data for *Trust to Healthcare Service* at region has been collected in 2018 services was gathered in 2018 as the most recent data set. But only a little variation has shifted when compared to the trend from 2016 to 2018. Therefore, the data on trust in healthcare services for each county that were gathered in 2018 were used in this study.

Stata statistical software has been used to analyse the hypothesis of this research paper. To evaluate the initial status of the collected explanatory variables, descriptive statistics were performed separately for the treatment and control groups. Please see the table below, Table 2. Demographic data between the treatment and control groups are similar in each category. On the other hand, the education level of treatment group has higher proportion of "Post secondary" than the control group. On the other hand, Trust to the healthcare by treatment counties have 58.5% while control counties have 62%.

Table 2: Descriptive statistics of the control and treatment group

Descriptive Statistics

	Treatment		Control	
	Mean	Std. Dev.	Mean	Std. Dev.
Male	.504	0	.506	.004
Female	.496	0	.494	.004
Foreign-born	.26	.053	.254	.063
Swedish born	.74	.053	.746	.063
Urbanization	.815	.055	.828	.043
Lower secondary	.328	0	.335	.012
Upper secondary	.329	.026	.345	.024
Post secondary	.305	.026	.284	.03
Mean income*	197.733	6.9	196.451	6.814
Trust	.585	.012	.62	.062
Vaccine uptake 16-17	.189	.269	.197	.271
Vaccine uptake18-29	.387	.344	.372	.33
Vaccine uptake 30-39	.423	.345	.419	.332

*Note: * Annual Incomes per '000 SEK. Vaccine uptake is in cumulative percentage.*

3.4 Method: Econometrics Strategies

A fundamental correlation analysis was conducted to assess the relationship between the independent and dependent variables. In academic contexts, it is commonly accepted that a correlation coefficient of 0.7 or greater indicates a high degree of correlation between variables. This is a widely recognized rule of thumb for assessing the strength of correlations. The presence of a strong correlation between exposures may suggest the existence of a confounding association that requires appropriate adjustment during the analysis. The findings indicate that there exists a correlation coefficient of 0.719 between Urbanization and Foreign Born. In other words, the estimated model should not include both the Urbanization and Foreign-Born variables at the same moment in order to avoid instabilities in the model's output.

Table 3. Correlation coefficients of the explanatory variables over Vaccine Uptake

Spearman's rank correlation coefficients

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
(1) Vaccine Uptake	1.000							
(2) Trust	0.035	1.000						
(3) Female	-0.102	0.039	1.000					
(4) Foreign Born	-0.273	0.159	0.463	1.000				
(5) Lower Secondary	-0.152	-0.164	0.304	0.458	1.000			
(6) Post Secondary	-0.001	0.355	0.044	0.223	**-0.667**	1.000		
(7) Urbanization	-0.187	0.060	0.393	**0.719**	0.154	0.357	1.000	
(8) Avg Income	-0.048	-0.069	0.056	0.189	-0.419	0.623	0.625	1.000

Spearman rho = 0.625

Prior to estimating any coefficients or conducting statistical analyses, an examination of the collected panel dataset was conducted. Panel data is characterized by the repeated measurement of the same units or counties at specific time intervals, such as weekly in this instance. Each county has unique characteristics that must be taken into account when assessing the correlation with SMS treatment. A panel data consisting of 17 units is generally regarded as a relatively small dataset. Time-invariant variables, such as the proportion of females and males, may also exert an influence on the impact in promoting vaccination. Simultaneously, time serves as the covariate for both SMS nudges and the outcome of vaccine uptake. Hence, it is plausible that the dataset may exhibit serial correlation and heteroscedasticity. The presence of autocorrelation within observations can lead to biased estimates of coefficients and unreliable statistical test results for hypotheses (Wing, Simon, & Bello-Gomez, 2018) . In the event that the panel data set exhibits heteroscedasticity, it is possible for the reliability of the inference to be impacted by the estimated standard errors, coefficients, and incorrect P value of the regression. In order to rectify these concerns, it is necessary to employ cluster standard errors in all stages of the regression analysis. (Wing et al., 2018). The utilization of the *"vce (cluster County)"* clustering command in panel data analysis allowed for the estimation of clustered standard errors, which accounted for the correlation within each group, while also controlling for potential heteroscedasticity and serial correlation (Baum, 2006).

3.4.1 Main model: Difference in differences

The quasi-experimental approach holds a similarity to the randomized trial, although lacking a controller or investigator, while attempting to mimic the characteristics of a randomized trial

(Gertler, Martinez, Premand, Rawlings, & Vermeersch, 2016). There are five widely used quasi-experimental methodologies, each of which has its own set of assumptions and restrictions. The selection of methodology is dependent upon the topic of research being pursued, the accessibility of data, and the characteristics of the treatment. Randomized controlled trials have been conducted to evaluate the effectiveness of SMS nudges in promoting compliance within a controlled environment. This study is a quasi-experimental investigation that utilizes empirical data sourced from a nationwide COVID-19 vaccine registry. Quasi-experimental studies, like randomized controlled trials, aim to assess the causal effect of a treatment by comparing outcomes between a treated group and a control group.

As mentioned, the research question is expecting to measure the definite impact of SMS nudge intervention in Sweden. Briefly, the impact can be measure by differencing between SMS nudge group and non-SMS nudge group. There are two possible quasi experimental methods to answer the question, (1) Difference in differences and (2) Synthetic control method. The difference-in-differences (DiD) methodology estimates the impact of an intervention by analyzing the differential changes in outcomes between two groups following the implementation of said intervention. The application of restrictions on the groups and time period through the DiD design can be utilized to address unmeasured confounding variables (Wing et al., 2018). This is to ensure that the unique characteristic of the counties are maintained and the time interruption is respected in the analysis. On the other hand, the synthetic control study is creating the dummy variables which are very similar to the treatment group and measure the net impact if there is no intervention in the treatment group. The main focus of synthetic control is the spectrum of the variables identified to mimic the treatment group rather than the absolute net impact (Janet, Peter, James, Mark, & Frank, 2018). For this study, we do have the empirical data of Non-SMS intervention counties (Control group), the difference in differences (DiD) approach become the most appropriate analysis to answer the question.

The present study employs the interaction term for difference-in-differences analysis and serves as the primary model for the study (Wing et al., 2018).

Model (1) – Difference in Differences

$$Vacccine\ Uptake_{it} = \alpha + \beta 1\,Treated_i + \beta 2\,Post_t + \beta 3\,Treated_i * Post_t + \varepsilon_{it}$$

Where i= country, t= weekly time interaction

The dependent variable (Y) is the COVID-19 vaccination uptake, denoted as *Vaccine* $Uptake_{jt}$. α is the constant of the difference in difference effect estimate when time is equal to 0. Two groups (i=1,2) are observed in two time periods (t=1,2) simply. Both groups were in the control stage for the period 1 while group 2 was given the intervention in period 2. In the DiD equation, $Treated_i$ has not subscripted with *t* since the only change among the group is time invariant. Likewise, the $Post_I$ indicates for period 2 (post period) without any subscription for the group since there is no difference in time among the groups. In the formula, β1 is the coefficient of changes in group effect and β2 is the changes of time effect. The treatment group variable is the inherent differences between treatment and control groups while the post variable is for the time trend, moving from pre to post intervention weeks. *"Treated*Post*" explanatory variable is the main variable for the DiD analysis which is the interaction term of the treated group at post intervention. That variable could explain that the interaction term of treatment effect which measures effectiveness of SMS nudge intervention in treated group's vaccine uptake. The timeframe for the analysis is from Week 26 (when >18 years were eligible to receive the vaccine) to Week 44 (after 6 weeks of the SMS nudge implementation). Hence, the period between weeks 26 and 38 is designated as the pre-SMS treatment phase, while the period spanning from weeks 39 to 44 is identified as the post-treatment phase.

The primary difference-in-differences (DiD) model was supported with stratifying analysis to ascertain the varying effects of the SMS intervention on three distinct age cohorts. Initially, a DiD regression analysis was conducted on the specified age cohort of 16–39 years old. Then, the analysis was expanded into three separate estimates by dividing the sample into three distinct age groups: 16 to 17 years, 18 to 29 years, and 30 to 39 years. The data on vaccine uptake was also categorized into three distinct age groups. This study elucidated that the efficacy of SMS interventions may vary depending on the age demographics of the recipients.

3.4.2 Robustness analyses: Panel data analysis (fixed effect and random effect)

As forementioned, the longitudinal panel data can be highly correlated therefore, some rules of effect must be applied. As per the nature of panel data set, the data have been controlled the group effect and time effect. Group effect in this case meant the county's unique characteristics within the counties and time effect was the SMS intervention week over counties. The varying confounders in the groups are time invariants and also the varying confounders in the time periods are the treatment invariants. The Pooled OLS effect is the least useful tactics for this research because it is assuming both treatment and control groups have same intercept and coefficient (Gertler et al., 2016). It ignores the fact of unobserved factors that differ from county to county.

With given panel data set, two differences can be investigated (1) difference in COVID-19 vaccination rate after SMS nudge treated among counties while controlling unobserved time varying factor- fixed effect (2) difference in COVID-19 vaccination rate after treated while considering heterogeneity of each county- random effect. Both fixed effect and DiD model omit explanatory variables' coefficient when they remain unchanged before and after period. Those two defined models are performed as supplement to main model, mentioned as Model (2) and Model (3). The linear equation for them are:

Model (2) – Fixed effect

$$Vaccine\ Uptake_{it} = \alpha_i + \beta 1 treatment*Period_{it} + \delta_t + u_i + \varepsilon_{it} + \beta X_{it}$$

Model (3) – Random effect

$$Vaccine\ Uptake_{it} = \alpha_i + \beta 1 treatment*Period_{it} + u_i + \varepsilon_{it} + \beta X_{it}$$

Vaccine Uptake$_{it}$ is outcome variable (for county i at time t) where α_i is the unknown intercept for each county and X_{it} is a vector of predictors (for county i at time t). δ_t is the unknow coefficient for the time regressors (t) u_i within-entity error term and ε_{it} overall error term. The reasoning of running panel data set analysis as supplementary model is necessary to explain. The random effect would allow to add time invariant regressors while fixed effect and DiD model would not. The random effect could be tested whether those added explanatory variables cause the impact of SMS nudge treatment.

For both models, when choosing between fixed effect "fe" and random effect "re", Hausman test was used. If the coefficient of fe and re are similar, the robustness of the results is somewhat reliable and the result support the arguments that the model is not sensitive to the changes of the estimation methods (Gertler et al., 2016). The result of the Hausman test of the study showed that the random effect is more suitable despite the coefficient of both fe and re are the same. The basis of the random effect is given a strong assumption of the observed and unobserved characteristics of the individual in panel data are not correlated which did not happen in this case. Therefore, despite the Hausman test result, the analysis does not solely rely on either random-effects or fixed effect, rather checking the robustness of the models' result by using different estimation methods.

In the later part of the analysis, the additional explanatory variables were added to the panel data random effect analysis. This step is to check the robustness of the analysis if the added variables are impacting to the SMS nudge treatment result. Explanatory variables are grouped into 3 groups (1) demographic status: sex, place of birth and degree of urbanization (2) socioeconomic status: average income and level of education (3) trust to healthcare service. Each group are added to the model individually and later, all of them are added to the model at once.

Demographic data, Sex (Male=0, Female=1), Place of birth (Swedish Born=0, Foreign Born=1) and Degree of Urbanization were collected in percentage over the population of 2021 of each county in Sweden. However, Foreign Born is highly correlated with degree of urbanization as per *Table 2*. Therefore, two models are run in respect to demographic variables called "*Demo"* (without Urbanization) and "*Demo1"* model (without place of birth) as an explanatory variable. % of Trust level to Healthcare Service in each county is added to random effect model as another test and run the analysis separately and called *"Trust to healthcare"* model. % level of education of each county is grouped into 3, Lower, Upper and Post-Secondary Level which are added to the random effect model to test the fitness of the model, called "SES1" model. Later "SES1" model is added with Average Income of 16-

39 years old of each county and named as "SES2". The model called *"All"* represents all the explanatories added together except Urbanization. The linear equations are listed in the *Appendix 2.*

3.5 Ethical consideration and conflict of interest declaration

The study is solely based on the secondary data available from the publicly available data source of Sweden and previous research studies. The data are the aggregate data without identified personal information, thus there was no risk of harm for individuals and no need for approval from an ethical review board to conduct the study.

4. Results

Graphical trends were created for the year 2021 to visualize the difference of vaccine uptake between treatment and control group. Two descriptive trend graphs are presented here, *Figure 3* emphasizes on the cumulative vaccination uptake and *Figure 4* shows the weekly vaccination uptake. The COVID-19 vaccine programme was commenced on Week 50, 2020 in Sweden. However, at county level, some counties have started immediately but other started a week later Week 51, 2020 due to delay in cold chain storage readiness to keep the vaccination.

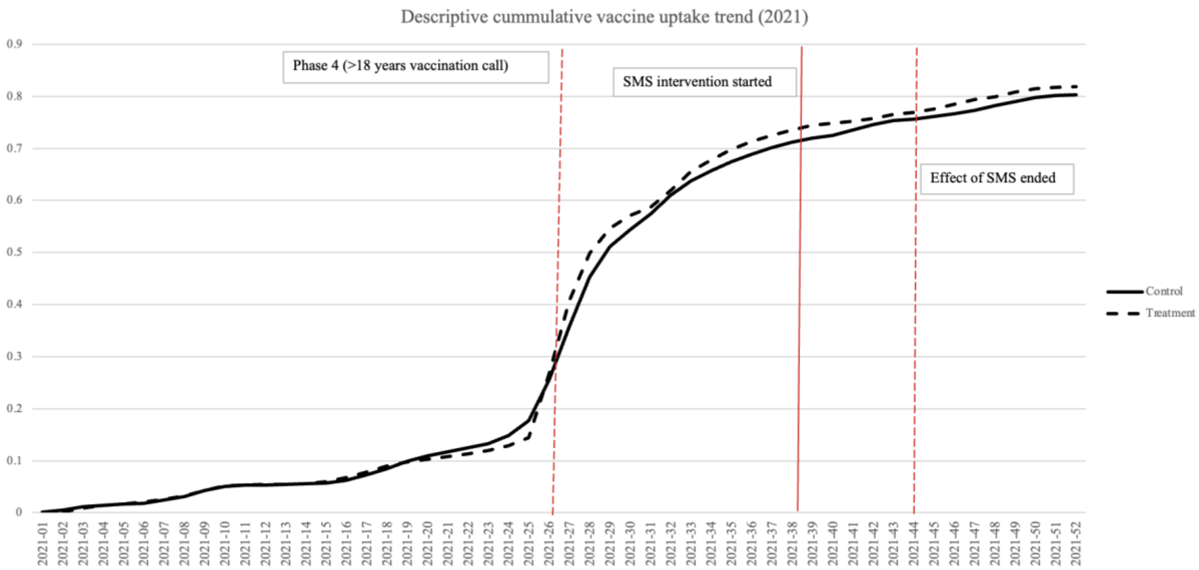

Figure 3. Descriptive trend graph of cumulative vaccine uptake for 2 groups between 16-39 years old

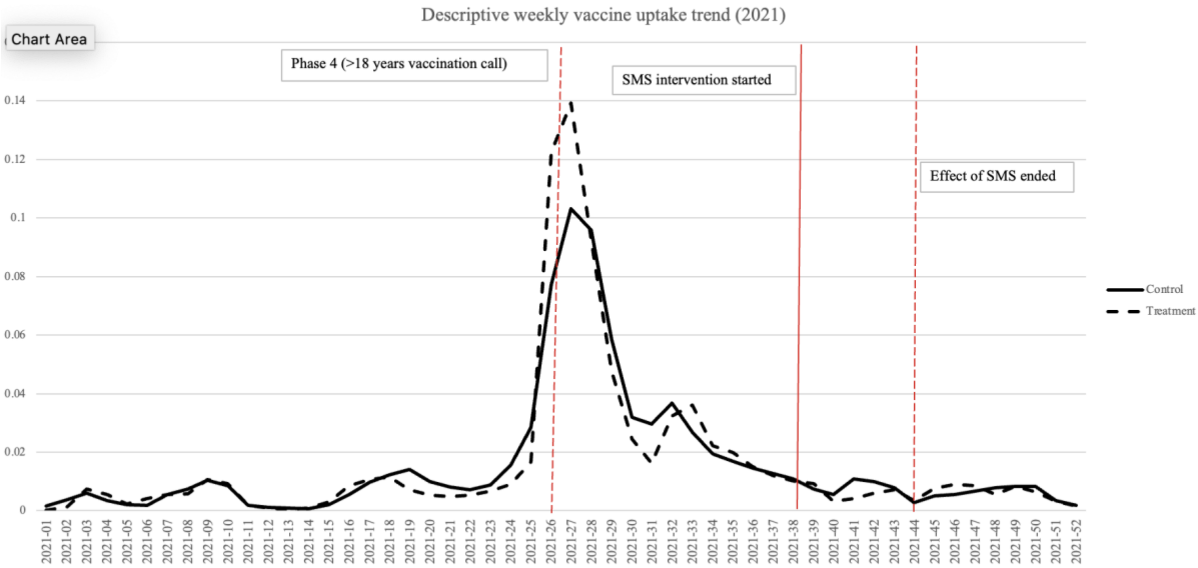

Figure 4. Descriptive trend graph of weekly vaccine uptake for 2 groups between 16-34 years old

The Y axis of both line graphs illustrates the percentage of vaccine uptake, while the X axis denotes the week of the year 2021. The trend lines represent the treatment group and control group. The commencement of phase 4 of the national vaccine program occurred during week 26, which involved the announcement of COVID-19 vaccine eligibility for individuals aged above 18 years.

The cumulative format of vaccine uptake outcome data is reflected in Figure 3, which displays upward trends across the weeks. The graphical representation indicates that the treatment group exhibited a greater cumulative uptake of vaccines in comparison to the control group during both the pre- and post-interventions of the SMS nudge intervention. Prior to the implementation of the intervention, the trend lines of the two groups displayed parallelism. In the 38th week of 2021, 73% of the population in the treatment group and 71% in the control group received the COVID-19 vaccine. The difference in vaccination rates between the two groups was approximately 2%. However, as of week 44 in 2021, there appears to be no statistically significant difference in the observed trends.

In *Figure 4*, it highlights the descriptive trend analysis, which focuses on the weekly vaccine uptake of both the treatment and control groups, taking into account the absolute vaccine rate. The weekly vaccination rates in both groups experienced a gradual decline from 10% to less than 1% between Week 26 and Week 44. This implies that a significant proportion of individuals in both cohorts had received their initial vaccination prior to the implementation of the SMS nudge intervention. It's interesting to see that the treatment group trend has a lower immunization rate for all weeks but the four from Weeks 33 to 36. Following the implementation of the SMS intervention during Week 38 of 2021, the data indicates that the treatment group has exhibited a lower weekly vaccination uptake compared to the control group.

The data indicates that the cumulative vaccine uptake during the period of interest, from Week 26 to Week 44, was higher in the treatment group compared to the control group. Upon analysis of the weekly vaccine uptake, as depicted in Figure 4, it was observed that most of the population in both cohorts promptly received the COVID-19 vaccine upon being summoned, which occurred approximately during week 26. However, it is noteworthy that the vaccine uptake exhibited a decline of considerable magnitude after a period of five weeks. Furthermore, after the implementation of the SMS nudge intervention, there has been a decrease in non-cumulative vaccine uptake. This can be attributed to a higher percentage of individuals in the treatment counties receiving the vaccine in Week 27 (14%) as opposed to the control group (10%).

4.1 Assumption of parallel trends

The prerequisite criteria of DiD study design is that prior to the intervention, the compared groups must fulfil parallel trends. The assumption is really that the two groups would have followed parallel trends after the interventions, had the intervention not occurred in the treatment group. However, because we cannot test this in the post-period, we try to assess parallel trends in the pre-period. Parallel trend before the intervention is to capture the similarity of outcome variables among the groups to perform further analysis on treatment effect (DIME, 2016a). To ensure the internal validity of the model, firstly, parallel trend is tested in this study (Wing et al., 2018).

In *Figure 5*, the observed means plot shows the mean vaccine uptake (%) for both groups in 2021. Before Week 38, 2021, the vaccine uptakes of two groups are trending parallelly. In linear-trends model, the estimated trend using a linear regression model with interaction terms of group and time shows no significant differences in trends between two groups before SMS intervention started. This indicates that both groups have the parallel trends before the intervention is implemented as a pre-requisite (DIME, 2016a) (DIME, 2016b) and the DiD approach for this study has been internally validated.

Granger test was performed to access the time varying effects, including the effects in anticipation of the intervention (i.e. before). The P value of the granger test is less than 0.5 (*Appendix 3*), meaning we are now more confident that our DiD estimates are accurate which tells us there is an impact on vaccine effect over the time.

After proving the pre trend analysis, the next step is to figure out the effect of the SMS intervention over COVID-19 vaccination in both groups which is the main part of the study. From the trend, both groups have similar trend line even after the intervention.

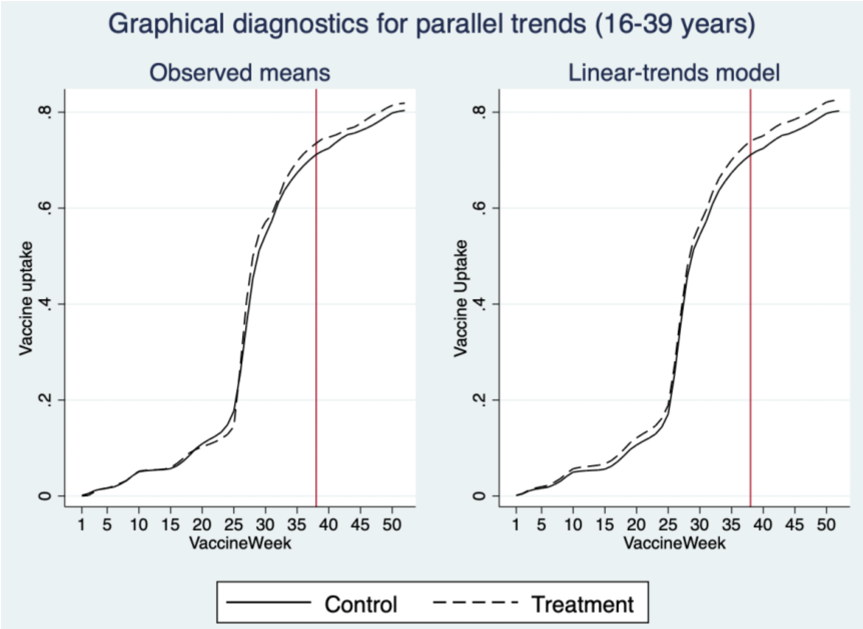

Figure 5. Parallel trend analysis between control and treatment groups before Week 38, 2021

After checking the prerequisite criteria of the models and data cleaning, the statistical tests for model (1) (2) and (3) have been performed.

4.2 Results from Differences-in-difference model and panel data models

On Week 38 of 2021, SMS nudge was made available in Värmland and Västra Götaland. The differences-in-difference regression result from Model 1 of *Table 4* is displayed while the group effect and time affected are being controlled. There is no statistically significant evidence to support the claim that the SMS nudge had an effect on the uptake of the COVID-19 vaccination due to the negative coefficient of -0.008 (0.025), which indicates that the SMS nudge decreased vaccine uptake. However, the coefficient is near zero with a wide confidence interval. According to the output, there is no statistically significant evidence to support the claim that SMS nudges would influence COVID-19 vaccine uptake in Sweden in 2021.

The panel data analysis with fixed effects (FE) and random effects (RE) is represented by models 2 and 3, respectively. The anticipated coefficient of the SMS nudge's effect is similar to model 1, with -0.0083 percentage points. The intercept (the constant) shows that before SMS was used, the control group's average uptake of the vaccination was 0.57 percentage points (p value 0.01). When the time effect is controlled for, the treated group had an average 0.025% higher vaccine uptake in the pre-period than the control group (non-significant). Please see *Table 4's* Model 3 column.

On the other hand, when the group effect is considered, the post-period vaccine uptake in the control group was on average 0.172 percentage points higher. In conclusion, using empirical data from 2021, there is no statistical evidence to suggest that the SMS nudge toward COVID-19 vaccination in Sweden has any effect.

Table 4. Results of Difference in differences model and panel data models (fixed effect and random effect)

	(Model 1) DiD	(Model 2) FE	(Model 3) RE
Treated	N/A	N/A	0.0252
			(-0.0798, 0.1302)
Post-period	N/A	0.1719***	0.1719***
		(0.1588, 0.1849)	(0.1598, 0.1839)
Treated x Post-period	-0.0083	-0.0083	-0.0083
	(-0.0620, 0.0454)	(-0.0606, 0.0439)	(-0.0567, 0.0401)
Constant	N/A	0.5703***	0.5673***
		(0.5662, 0.5744)	(0.5509, 0.5837)
Observations	323	323	323
R-squared	N/A	0.3045	0.3077

95% Confident interval in parentheses

*** p<0.01, ** p<0.05, *p<0.1

Note: The period covered for these 3 models is from Week 26, 2021 to Week 44, 2021 with SMS nudge interrupted at Week 38, 2021. The targeted aged group was 16 to 39 years old at the time of 2021 in both treatment and control groups.

4.3 Results from stratifying the age groups

The main model result shows ignorable (or) close to zero impact of SMS nudge is found for the age of 16-39 inhabitants in Sweden. Despite the result from main model, further in-depth analysis could be run by stratifying the cohort into different age group. We could expect that SMS nudge might impact differently to stratified groups. Therefore, the data were stratified and grouped into three clusters depending on age range. Three age groups have been stratified, 16-17 years, 18-29 years and 30-39 years along with the cumulative weekly vaccine uptake's grouping. The parallel trends test are performed before analysing with DiD approach, *Appendix 4*. The resulted coefficients of the stratified treated groups after the SMS nudge (Treatment 1 x Period 1) are varied as expected. -0.0368 and -0.0143 percentage point are observed for 16-17 and 18-29 age groups however, we observed positive value 0.0049 in 30-39 group. In summary, SMS nudge intervention towards COVID-19 vaccine uptake for age group of 30-39 in Sweden varied between -0.055 to 0.07 percentage point with best estimation of 0.0049. 0.0049 percentage point of cumulative COVID-19 vaccine uptake is higher in the 30-39 year treated group compared to the control when the other factors remain constant. However, none of those coefficients are statistically significant to say there is an impact in vaccine uptake due to SMS nudge intervention. Below *Figure 6* is the observed coefficients of each aged group with 95% CI *and Table 5* are the results from the STATA for reference.

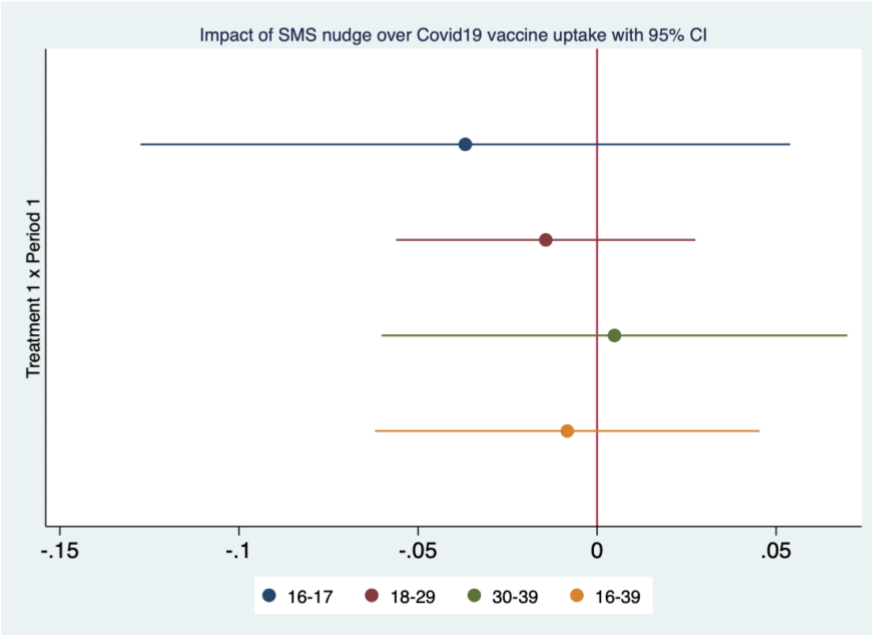

Figure 6. SMS impact on different age groups with 95% confident interval

Table 5. Results of stratifying the age groups of the main model (DiD)

	DiD (1) Age 16-39	(2) Age 16-17	(3) Age 18-29	(4) Age 30-39
Treated x Post-period	-0.0083	-0.0368	-0.0143	0.0049
	(0.0253)	(0.0428)	(0.0197)	(0.0307)
Constant	0.2559***	0.0000	0.1726***	0.3896***
	(0.0108)	(0.0060)	(0.0058)	(0.0210)
Observations	323	323	323	323

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1
Note: The period covered for these 4 columns is from Week 26, 2021 to Week 44, 2021 with SMS nudge interrupted at Week 38, 2021. The standard errors displayed in the table are robust standard errors.

4.4 Results from alternative timeframe to Differences-in-difference model

Three additional timelines of data sets were included for the sensitivity analysis in addition to the main dataset, which covered Weeks 26 to 44. The main dataset uses a 19-week period, and supplemental analyses use 8-week periods (W34-42), 31-week periods (W20-50), and 52-week periods (W1-W52).

In the SMS-treated group, vaccination uptake decreased by -0.0048 percentage points across the short timeframe of 8 weeks. The estimate was 95% certain to be between -0,0223 and 0.0126 percentage points. On the other hand, the findings from evaluating longer time frames (31 weeks and 52 weeks) show that the SMS nudge intervention had a positive effect on the treated group's uptake of the vaccine. However, the calculated coefficients are very near to zero, 0.0049 and 0.0104, respectively. Meaning to say, none of the additional timeframe analyses was significant to say that SMS nudge was impacting the increasing vaccine uptake.

These estimations are quite similar to descriptive analysis. Vaccine uptake was at 15% in the treatment and 10% in the control group at week 27, after 18 years old and above were eligible for vaccination (Ref, *Figure 4*). The cumulative vaccination uptake graph also showed that, throughout 2021, except for the five-week period from Week 20 to 25, the treatment group showed higher cumulative uptake than the control group. Thus, we have lack of evidence to state that the slightly positive impacts (from 31 weeks and 52 weeks timeframe analyses) could be due to the SMS nudge by which the highest vaccine rate happened before SMS nudge was introduced. The observed coefficients for each timeframe are shown in *Figure 7* below, along with 95% confidence intervals. *Table 5* has STATA findings for reference.

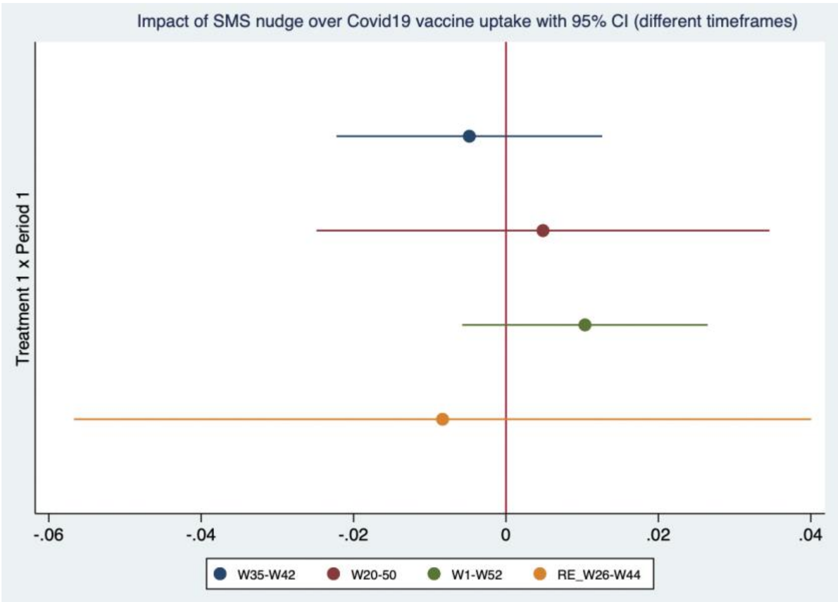

Figure 7. SMS impact on different timeframes with 95% confident interval

Table 6. Results from DiD analysis of different timeframes

	(1) DiD_W26-W44	(3) W35-W42	(5) W20-W50	(7) W1-W52
Treated x Post-period	-0.0083	-0.0048	0.0049	0.0104

	(0.0253)	(0.0091)	(0.0156)	(0.0085)
Constant	0.2559***	0.6766***	0.1082***	0.0014
	(0.0108)	(0.0020)	(0.0061)	(0.0055)
Observations	323	136	527	884

Robust standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

4.5 Results from adding regressors to random effect model

As discussed in the method's session, a different set of regressors is added to the model to test its robustness. This aims to see if those time-invariant factors have a direct impact on COVID-19 vaccine uptake.

4.5.1 Demographic regressors in the RE model

The Demo1 model demonstrates that a 1% increase in females leads to a 1.7804 percentage point increase in COVID-19 vaccination uptake (up to 4.942 percentage points at 95% CI). However, in Demo 2, the female percentage showed a negative impact on COVID-19 vaccine uptake. Therefore, we are unsure whether a country with a higher female proportion influences vaccination uptake at this time.

In Demo 1, the "Foreign Born" variable had a negative impact on COVID-19 vaccination with coefficients of -0.4877 (P values less than 0.001) which is the most significant point to take note. The degree of urbanization is also trending downward, from -0.7629 to 0.0286 with a P value less than 0.1. Every 1% increase in urbanization could result in a decline in vaccination uptake ranging from -0.7629 to 0.02386 percentage points, with -0.3672 being our best forecast. As a result, increasing urbanization is part of the migration, partly reacting to the negative.

4.5.2 Trust in healthcare services regressor in the RE model

Trust in healthcare services reveals a favorable effect of vaccination. For every one percentage point gain in trust in the healthcare system at the county level, vaccine uptake might increase by 0.1695 units. Though we do not have enough statistical data to establish it, the estimates might be anywhere between -0.0382 and 0.3773 units within 95% confidence ranges.

4.5.3 Socioeconomic status regressors in the RE model

According to the results of SES1 and SES2, the higher the education level, the bigger the impact on immunization. In both the SES1 and SES2 models, the proportion of upper secondary education in the population had the greatest impact on education level, with 3.14 units (P value 0.1) and 3.59 units (P value 0.05), respectively. In SES2, the county's average income has essentially no effect on COVID-19 vaccine uptake.

4.5.4 All regressors in the RE model

According to the results of the All model, when the proportion of foreign-born population in the counties increases by one percentage point, vaccination uptake could fall to 1.3788 units (at the lower bound of the 95% CI). This is the most important discovery in our study. This observation is fairly consistent with Demo 1. Also, in Figure 1, Stockholm, VGR, and Skäne have lower vaccine uptake compared to other counties, and these counties have a larger proportion of foreign-born residents.

To finish the robustness test, "Place of Birth" is a factor that influences vaccination. This explains why the county with the highest number of "foreign-born" people should make an extra effort to promote COVID-19 vaccination. The study's findings demonstrate an indirect association between the proportion of foreign-born children and vaccination uptake, with -0.6846 percentage points at the lower bound. Urbanization is also related to a high migratory population, which has a negative influence on vaccination uptake by -0.3672%. The effect of the proportion of females in the county and the degree of education on vaccination uptake is uncertain, and more research is recommended. Below *Table 7* are the results from the STATA for reference.

The coefficient for interaction term in all the models are the same in all the tested models and the yields are in the similar estimates. This is resulted because

(1) the regressors added were time-invariant variables in which they were constant pre and post of the SMS intervention.
(2) the unique features of the counties within treatment and control groups were varied which represent heterogeneity of the group effect.

Table 7. Results from adding regressors in RE model

	(1) RE	(2) Demo1	(3) Demo2	(4) Trust	(5) SES1	(6) SES2	(7) All
Treated x Post period	-0.0083	-0.0083	-0.0083	-0.0083	-0.0083	-0.0083	-0.0083
	(0.0247)	(0.0248)	(0.0248)	(0.0247)	(0.0248)	(0.0248)	(0.0250)
Female		1.7807	-0.7481				0.9545
		(1.6130)	(2.2778)				(1.9718)
Foreign Born		-0.4877***					-0.8116***
		(0.1005)					(0.2894)
Urbanization			-0.3672*				
			(0.2019)				
Trust				0.0636			0.1695

				(0.1329)			(0.1060)
Lower Secondary					1.1995	1.7532	-0.1606
					(2.7816)	(2.7483)	(1.8338)
Upper Secondary					3.1404*	3.5955**	-2.0532
					(1.8775)	(1.8272)	(2.3811)
Post-Secondary					2.5627	3.2517	-1.2900
					(2.2801)	(2.1943)	(2.1475)
Avg Income						-0.0013*	-0.0007
						(0.0008)	(0.0008)
Constant	0.5673***	-0.1891	1.2411	0.5279***	-1.6466	-1.7975	1.5261
	(0.0084)	(0.7803)	(1.0877)	(0.0825)	(2.2099)	(2.1678)	(2.4079)
Observations	323	323	323	323	323	323	323
Number of County_n	17	17	17	17	17	17	17

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1
Note: Time in the analysis is from Week 26 to Week 44 for targeted age group of 16-39 years old.

5. Discussion

5.1 Discussions in comparisons with previous studies results

The present study aimed to assess the impact of an SMS nudge intervention on the uptake of Covid19 vaccination. The findings suggest that the effect of the SMS nudge was restricted, and in some cases, it even exhibited an adverse effect. The findings of the study exhibit robustness even after conducting analyses on stratified age groups, manipulating the time window, and introducing covariates. The findings from the county-level analyses indicate that the introduction of SMS nudges in Sweden for individuals aged 16-39 years old has resulted in a vaccination rate effect ranging from -0.0567 to 0.0401 percentage points.

However, pre-booking appointments with fixed schedules has been found to have a significant impact of 11.7 percentage points on increasing vaccine uptake, as compared to a synthetic-based approach in Sweden (Bonander et al., 2022). The observed discrepancy may be attributed to the pre-scheduled timeslot, which activated the simulation for vaccination reception. Stated differently, the letter functioned as a "Summon" and elicited a response of apprehension regarding the potential loss of opportunity. In contrast to our investigation, the letter nudge was dispatched during Week 30 of the year 2021, precisely one week subsequent to the summons for vaccination of individuals over the age of 18 in Uppsala County. We observed the negative association between oreign born and COVID-19 vaccination with -0.8116 percentage points in our study, Bonander et al's paper resulted similar discussion. Among 16-17 years old in 15 counties of Sweden, for 1% increased in Foreign born could lead negative vaccination percentage by -0.5811 on average.

In another study, the provision of a 200 SEK monetary incentive resulted in a 4.2 percentage point increase in vaccine uptake from a baseline of 71.6 percent in Sweden (Campos-Mercade et al., 2021). The payment was directed towards individuals aged between 18 and 49 years, a demographic that overlaps with the majority of our study's intended target group. The outcomes of Campos-Mercade is diverged from the findings of our study. The potential explanation for this phenomenon may be attributed to varying methods of implementing nudges. The goal of SMS nudge, in contrast to monetary incentive nudge, was to encourage people to get immunized while also fostering a positive thought process that would lead to a change in behavior. The same study analyzed other 3 behavioral nudges but effect to vaccination rate had only small and not significant which is the same result as this study (Campos-Mercade et al., 2021).

In another study, the utilization of text-based reminders may have a greater impact on vaccination rates during the initial stages of the vaccine program when compared to the later stages (Dai et al., 2021). The vaccination rate has demonstrated a 3.57 percentage point increase within a four-week period subsequent to the initial text message. However, the second reminder did not yield a vaccine uptake as substantial as the first SMS (Dai et al., 2021). Also, the participant of Dai et al (2021) were Healthcare staffs. It is possible that healthcare staffs possess a greater level of understanding regarding vaccination in comparison to other occupational groups. In the United States, healthcare personnel were identified as a priority group for COVID-19 vaccination. Both authors highlighted that the randomized controlled trials (RCTs) were carried out immediately after the vaccination eligible announcement, in contrast to our study which observed a 12-week interval after the vaccination call for individuals aged 18 years and above in the treated counties.

5.2 Strengths and limitations of the study

An aspect of merit in this thesis is its examination of the empirical dataset. The plausibility of the data set is deemed high as it is derived from a dependable public registry of empirical information. The difference-in-differences methodology has undergone rigorous testing and has satisfied the prerequisite of parallel trends. As a result, the estimated outcomes have been determined to be reliable and possess a high degree of precision. The selected covariates are publicly accessible data that exhibit a high degree of reliability. In general, the handling of data, analytical approach, and execution of sensitivity analysis demonstrate robustness and a significant level of reliability. Given that the dataset exhibits sufficient representativeness at the national level, the findings of this study might be perceived as generalizable and suitable for replication in other evaluations relating to the implementation of nudge strategies.

The method has its limitation. The difference-in-differences can only be performed if both control and treatment groups have similar characteristics in both pre and post period of the intervention. Thus, based on the estimated results, it can be confidently concluded that the intervention implemented is the cause of the observed causal impact between the two groups. If the synthetic control method was applied, the results cannot be so much difference as well since the obtained covariates are very similar in characteristic in the treatment group compared to control.

Parallel trend test was satisfied in the context of this investigation. Given the limited duration of the SMS intervention and its effectiveness, the confounding variables observed in the study were time-invariant, such as the proportion of gender and birthplace across different counties. Furthermore, the variable that is subject to change over time in the aforementioned approach is the SMS intervention. Therefore, the method itself limits some of the unobserved variables. For example, there might be some nudges (similar or different kind as SMS) implemented at the same time in the control and treatment groups which this method has been limited.

Every study has its limitation, so does this study. The SMS were delivered by referring to the hospital registries in both counties. We could assume to have different level of estimates if we use different registries to deliver the same SMS. The tested covariates are quality data but there might have other unobserved covariates those could affect to the vaccination. Further multi-level statistical analysis can be done to analyze the association between the level of education and vaccine uptake. Due to time constraint, this was not performed in the study. When nudge data were collected, the source data were publicized newsletters from the regional website. Therefore, the only information for the SMS text message was the targeted population and the timing without the wordings of actual message received by the inhabitants. Randomized control trial has explained that different kind of message is attracting people to make decisions differently (Patel, Milkman, et al., 2022). Apart from the group with summoned SMS, other groups received messages with "ownership sense" and "Reserved for you" reacted most to the nudge and got vaccination (Patel, Milkman, et al., 2022). With the actual wordings of the text message, we might analyse further in comparison with this study.

The evidence from (Dai et al., 2021) and (Patel, Fogel, et al., 2022) were highlighting the needs of immediate implementation in order the SMS text nudge to be effective in vaccination. Therefore, to be an effective implementation of SMS nudge, the policy makers should decide to implement as immediately as possible and compare the impact with base line estimation. Another factor is to be mindful of the language used in the text massage suggested by these papers (Reñosa et al., 2021) and (Patel, Milkman, et al., 2022).

6 Conclusion

To conclude our study, we observed the impact of SMS nudge intervention towards COVID-19 vaccination rate in Västra Götaland Region and Värmland was close to zero and the estimates are between -0.0567 to 0.0401 percentage points. The main analysis is from Week 26 to 44, 12 weeks before SMS intervention and 6 weeks after. The shorter time period of 8 weeks, not including the peak vaccine rate of Week 27, also impacting the vaccine uptake negatively too. We find no evidence that the vaccine uptake increased was due to the SMS nudge. People were taking vaccination without relying on the SMS nudge they received. The estimated result of no impact towards vaccination might potentially be due to waiting too long to implement SMS nudge in this study.

Counties with higher Foreign Born proportion than the average have to put extra effort to reach to the population who are hesitant to get COVID-19 vaccination. And we expected to be the same correlation in "Degree of Urbanization" and vaccine uptake. Further multilevel regression analysis is required to judge the relationship of Sex, level of education and other unobserved variables with the COVID-19 vaccination uptake.

7 Public Health Perceptive

Nudges are a commonly employed tool in public health interventions, spanning a range of initiatives from road safety and tobacco campaigns to immunization programs. The significant findings from this investigation have been duly produced. To get the intended results from nudges, policymakers, decision architects, must understand the meaning behind nudges, the timing of implementation, longevity of the nudge impact, and other factors. The findings of this study reveal that the implementation of SMS nudges may not be necessary when the baseline vaccination rate has already reached or exceeded 70% coverage within the population. The timely delivery of SMS nudges to the intended group is crucial in ensuring that relevant issues and events are addressed within a restricted timeframe, without excessive delaying in implementation. Those nudge related facts are important to consider to accomplish the effective public health interventions. After implementation of the intervention, the adequate follow up timeline should be set to evaluate the impact and causal effect of implemented intervention.

This research attempts to investigate the potential impact of SMS nudges on COVID-19 vaccination rates. In public health sectors, SMS has been used as a tool to communicate with patients, and to remind the healthcare appointment and vaccination. There are many types of implementations to choose from, based on the available resources to pursue vaccination. Irrespective of the specific approach employed, it is crucial to assess the efficacy of the implementation. This research employed Thaler's (2008) Nudge theoretical framework and assessed the practical implementation outcomes in Sweden's real-world context. Hence, from a public health standpoint, policymakers should be advised to engage in comprehensive planning, as suggested by this study, prior to the implementation of SMS nudges. Furthermore, it is imperative to replicate the aforementioned methodology in order to assess the efficacy of alternative forms of nudges.

8 Acknowledgement

This study will not be completed without the guidance from Naimi, my supervisor. I was not confident to take on econometrics' aspect of analyses as much as I was in Health economics modelling. But the thesis paper turns out sufficient for me to know how econometrics are as important as modelling, especially when policy makers are not aware of the effectiveness of the implementations and when the research budget are limited to perform RCT. I also learn that these methods are very appreciative in healthcare evaluation without consuming so much time yet the results are as good as RCT. Special thanks to Carls Bonander. His paper called "Vaccination nudges: A study of pre-booked COVID-19 vaccination in Sweden" was an inspiration for me to come up with this thesis research question. I have used his lectuers and reading materials again which I neglected during "online" lectures and my focus was Carls' cats during the lectures sessions.

My family members and my dear husband who are very supportive to me throughout the thesis journey. They are the people who endured with me and stood by me despite of my ever swinging moods.

I also thank to my study and thesis writing buddies, especially Sneha, who showed up to the library with grumpy faces sometimes, lots of complaints for things-did-not-work-out-as-plan, encouragements, and anxieties at the same time. I heart them. Whatever the results are, "All is well".

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10 Appendix

Appendix 1

<table>
<tr><th>Treatment counties</th><th>Control counties</th><th colspan="2">Excluded counties</th></tr>
<tr><td rowspan="3">Västra Götaland
Värmland

- Total 2 counties. SMS to Specific groups with lower uptake, using different registers. No matter the previous vaccine status.</td><td rowspan="3">Sörmland
Östergötland
Kronoberg
Kalmar
Blekinge
Skåne
Hallands
Örebro
Västmanland
Dalarnas
Gävleborg
Västernorrlands
Jämtland
Västerbottens
Norrbotten

- Total 15 counties. No SMS nudge was implemented in these counties</td><td>Stockholm
Gotland</td><td>Reminder SMS is sent through “Always open- Alltid öppet” application to book for top-up dose</td></tr>
<tr><td>Uppsala</td><td>Reminder SMS is sent to whom registered on 1177.se and subscribed for notification</td></tr>
<tr><td>Jönköping</td><td>No information on region’s web</td></tr>
</table>

Appendix 2

Demo1 model

$$Vaccine\ Uptake_{it} = \alpha_i + \beta 1 treatment*Period_{it} + \beta 2 Sex_{it} + \beta 3 PlaceOfBirth_{it} + u_i + \varepsilon_{it}$$

Demo2 model

$$Vaccine\ Uptake_{it} = \alpha_i + \beta 1 treatment*Period_{it} + \beta 2 Sex_{it} + \beta 3 Urbanization_{it} + u_i + \varepsilon_{it}$$

Trust to healthcare model

$$Vaccine\ Uptake_{it} = \alpha_i + \beta 1 treatment*Period_{it} + \beta 2 Trust_{it} + u_i + \varepsilon_{it}$$

SES1 model

$$Vaccine\ Uptake_{it} = \alpha_i + \beta 1 treatment*Period_{it} + \beta 2 Education_{it} + u_i + \varepsilon_{it}$$

SES2 model

$$Vaccine\ Uptake_{it} = \alpha_i + \beta 1 treatment*Period_{it} + \beta 2 Education_{it} + \beta 3 AvgIncome_{it} + u_i + \varepsilon_{it}$$

All model

$$Vaccine\ Uptake_{it} = \alpha_i + \beta 1 treatment*Period_{it} + \beta 2 Sex_{it} + \beta 3 PlaceOfBirth_{it} + \beta 4 Education_{it} + \beta 5 AvgIncome_{it} + \beta 6 Trust_{it} + u_i + \varepsilon_{it}$$

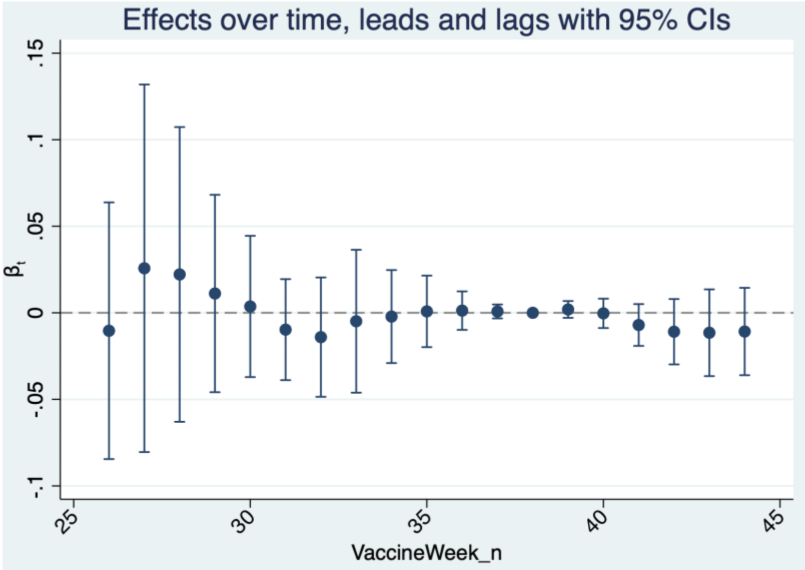
Appendix 3

Granger causality test

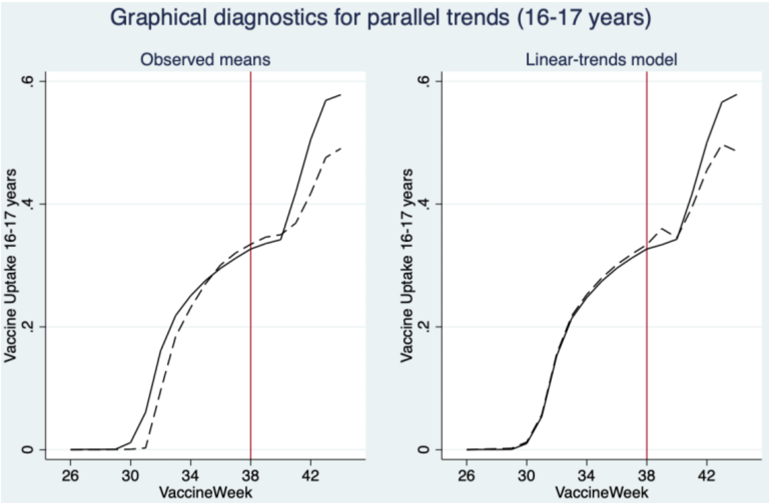
H0: No effect in anticipation of treatment

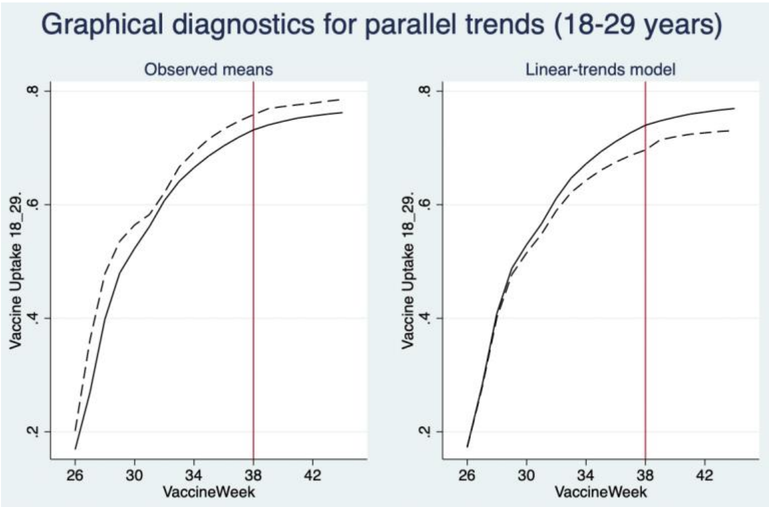
F(12, 16) = 79.68

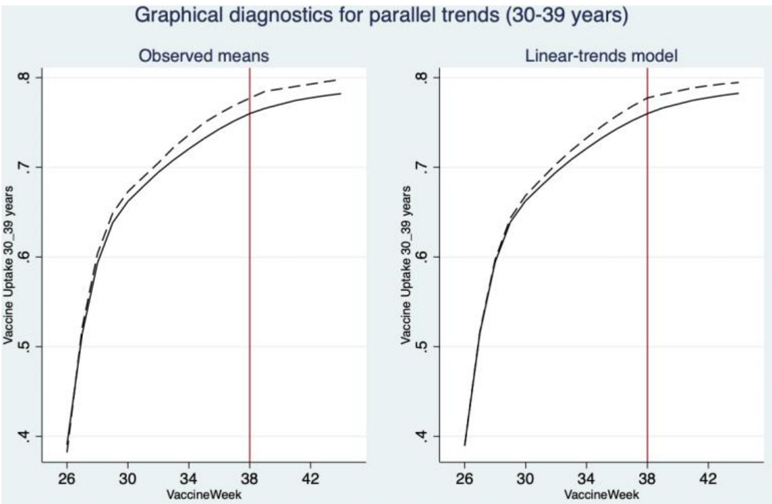
Prob > F = 0.0000



Appendix 4


Graphical diagnostics for parallel trends (16-17 years)
Observed means
Linear-trends model
Vaccine Uptake 16-17 years
VaccineWeek


Graphical diagnostics for parallel trends (18-29 years)
Observed means
Linear-trends model
Vaccine Uptake 18_29.
VaccineWeek


Graphical diagnostics for parallel trends (30-39 years)
Observed means
Linear-trends model
Vaccine Uptake 30_39 years
VaccineWeek