Article

Were there long-term economic effects of exposure to polio vaccination? An analysis of migrants to Sweden 1946–2003☆

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ABSTRACT

Recent research showed that exposure to the vaccine against polio in early life had no long-term economic benefits among native Swedes. However, whether this result holds for individuals from other countries remains unexplored. This study explores the relationship between exposure to the vaccine and later-life outcomes, but focuses on individuals who migrated to Sweden (birth cohorts 1946–1971), and constitute a diverse sample in terms of national origin. Using a differences-in-differences approach and register data from the Swedish Longitudinal Immigrant Database, this study explores if being exposed to the vaccine against polio in the year of birth in the country of origin has any impact on adult income, educational achievement, or days or number of hospitalizations. The results are in line with the previous research in showing that there are no statistically significant effects on adult income, education, or health from exposure to the vaccine against polio, regardless of national origin. Furthermore, no scarring effects of exposure to polio epidemics were found on any of the outcomes, reinforcing the hypothesis that polio did not scar individuals in the same way as other contemporary epidemic diseases did, and that the lack of scarring could explain the absence of long-term impact from vaccine exposure.

1. Introduction

During the first half of the twentieth century, polio epidemic outbreaks were a universal and ever-present threat to public health. The paralytic consequences of the disease were well known and feared by all, especially parents of young children, since those in the first years of life were particularly vulnerable to infections. Extensive research efforts led to the development of two vaccines, in 1955 and 1961 respectively, which provided immunity against the disease (Sabin, 1962a; Salk, 1955). Since then, intensive vaccination campaigns around the globe have eradicated polio from all but three countries, preventing millions of infections and the needless life-long suffering of thousands of paralyzed children. The vaccine has proven to be extremely effective in providing long-term immunity, and it remains in the list of essential medicines

from the World Health Organization, which recommends all children worldwide to be immunized (World-Health-Organization, 2017).

While the short-term benefits of the vaccine are undeniable, recent research has looked into the existence of long-term economic effects from exposure to immunization. The starting point of this kind of analysis is that early life (pre- and postnatal environments) is a critical period for human capital formation (Almond, Currie, & Duque, 2018), and exposure to epidemics during this period of life, regardless of actual infection, has been shown to negatively impact, or scar, adult outcomes (Bengtsson & Broström, 2009; Helgertz & Bengtsson, 2019; Quaranta, 2013, 2014; Myrskylä et al., 2013), therefore removing the potential damage of epidemics, in this case via vaccination, could reasonably be expected to have the opposite effect on the future outcomes of children. Serratos-Sotelo, Bengtsson, and Nilsson (2019) show that, for the case of

native Swedes exposed to the 1957 vaccination campaign, this was not the case. Their analysis show that exposure to the vaccine against polio doesn't seem to have any long-term effect on adult income, educational achievement, or health, and the authors attribute this lack of effect to the apparent non-scarring nature of exposure to polio epidemics. Their conclusion is that, among native Swedes, children exposed to a polio epidemic who managed to avoid the paralytic symptoms made a full recovery (both medically and economically) and did not see their future prospects affected in any significant way.

While this might be the case for native Swedes, there is reason to doubt the results could hold for other nationalities, mostly because epidemics and the responses to them varied at the national level. For instance, not all countries had epidemics with similar virulence, some were hit harder than others, and there were slight differences in the viruses that were native or indigenous to different parts of the world. Also the level of industrialization and sanitation, as will be discussed later, affected the population's natural resistance to the disease and, therefore, its epidemic outbreaks. In general it makes sense that a study would include individuals with diverse national origins to test if the results from Serratos-Sotelo et al. (2019) are country-specific.

The present study, consequently, attempts at filling that gap, by asking whether exposure to the polio vaccine had any effect on adult outcomes of individuals from different countries. In order to find an answer, it uses data from the Swedish Longitudinal Immigrant Database (SLI) that contains economic and demographic information for a representative sample of individuals (birth cohorts 1946–1971) from several different countries who, at some point during their life, migrated to Sweden, as well as a reference group of native Swedes. I, then, use a differences-in-differences (DiD) methodology to exploit the plausibly exogenous time variation in the introduction of the vaccine against polio across different countries.

The results coincide with recent research in finding no significant long-term impact of exposure to the polio vaccine in early-life on adult economic outcomes. By using a diverse sample with individuals from different nationalities, this study finds that the lack of long-term effect of the vaccine is not origin-specific, but appears to be disease-related in the sense that while polio infections where extremely common before the vaccine, those who avoided the paralytic symptoms (a vast majority) were able to fully recover and suffered no long-term scarring.

In the next sections, I describe the context of this study, paying special attention to the disease in question, the development of the vaccine against it, and the way in which each of the countries in the sample implemented their first mass immunization campaigns. After presenting the details of the data and methodology used in this paper, I proceed to present and discuss the results of the main analysis, which show that the vaccine had no long-term impact on the outcomes studied, and of a secondary analysis, in which I show that exposure to polio epidemic outbreaks exhibits no long-term scarring effects.

2. Context

2.1. Poliomyelitis, epidemics, and vaccine development

Acute Poliomyelitis is an infectious disease caused by exposure to any of the three variants of the enterovirus known as *poliovirus* (Nathanson & Martin, 1979). The virus transmits mainly via the oral-fecal route, and undergoes replication in the digestive tract for a few days, before attacking the nervous system. Infection with poliovirus leads to one of two scenarios. In the first and most common of these, referred to as "inapparent infection", a person suffers from mild to moderate symptoms similar to those of a flu (fever, headaches, muscle stiffness), followed by a successful immune response and a complete recovery. In the second, rarest (around 1% of total infections), but most well-known scenario, the immune response is not sufficient to stop the virus, which continues to replicate and attack nerve tissue, especially the one in the grey matter of the spinal cord. Damage to the spinal cord

motor neurons, irreversible in nature, results in different degrees of muscle strength loss, which can range from weakness to outright paralysis. Mortality is highest among patients whose paralysis reaches the diaphragm, compromising autonomous breathing, but is overall considered a rare consequence of the disease. Once infection occurs, there is no known cure for the disease (Paul, 1971).

The history of Poliomyelitis (*polio,* for short) speaks both of the degree of industrialization and connection that human society has achieved. For the most part of human civilization, sanitation and waste disposal were so poor that practically everyone was exposed to the virus at an early age while still enjoying maternal immune protection, resulting in a surviving population that acquired a *natural immunity* of sorts (Zinkernagel, 2001). During these periods of time the disease was considered more of an endemic phenomenon in certain parts of the world. After the improvement of sanitation in most industrialized and industrializing nations during the late 19*th* and early 20*th* centuries, the early exposure to the virus disappeared along with the natural protection against it. It was in this period of time when outbreaks of Polio began appearing with increased frequency and strength (Smallman-Raynor & Cliff, 2006). International and intercontinental travels made matters worse, introducing strains of the virus native to other parts of the world for which local populations had absolutely no defense. By the first half of the 20th century, Polio epidemics became an important matter of public health, and understanding of the disease was urged among the scientific community, with the sight set on developing a vaccine, given that this type of preventive treatment had worked against some of the worst diseases of the time, such as smallpox, rabies, and tetanus (Paul, 1971).

Scientific inquiry about polio rapidly showed progress, first in identifying the transmission mechanism (water and food were the culprits, not air as an early hypothesis stated), then in understanding its pathology and epidemic characteristics, and finally in ascertaining the way in which the virus grew on and damaged the nerve tissue inside the spinal cord. The main hurdle on the path to a vaccine was that the virus seemed able to grow only on live nerve tissue, until research by Enders, Weller, and Robbins (1949) succeeded in overcoming this obstacle. Briefly afterwards, research started developing and testing vaccines in several countries simultaneously and rather independently. The first to succeed would be Jonas Salk, an American virologist, who developed an injected vaccine using killed virus that was declared safe for humans in April 1955 (Salk, 1955). Many countries decided to start using the Salk vaccine almost immediately, and it remained the main vaccine in use globally until the *live* vaccine developed by Albert Sabin was declared safe in 1961 (Sabin, 1965). While the Salk vaccine was the first in use, and it was responsible for eradication in most developed countries, the Sabin vaccine was vital in fighting polio in the developing and underdeveloped world since it's live (and weakened) virus allows the vaccine to be administered orally, sometimes even by dropping a dose on sugar cubes, while the killed virus in Salk's vaccine required intramuscular or subcutaneous injection (and the use of sterile needles). Both vaccines provide immunity to the disease and prevent any paralysis, with the Sabin live vaccine having the added benefit of also providing protection against the initial intestinal infection (Gothefors, 2008; Paul, 1971).

2.2. Vaccination campaigns

This paper uses, as part of the identification strategy, the time-variation in the introduction of the polio vaccine across a sample of 10 countries. In this subsection, the process in which the vaccine made its entry in each country is described, with special interest in the first mass vaccination campaign for each one of them. I differentiate this from small or local trials to really appreciate when the total of the population most at-risk became exposed to the protection afforded by the inoculation. For this reason, in this paper, whenever reference is made to "vaccine introduction in country *X*" it refers to the first mass vaccination campaign in said country. For a list of the countries included

in this study, as well as for a quick summary of important vaccine-related dates, please see Table 1.

As previously mentioned, it was the research of Jonas Salk at the U.S. National Foundation for Infantile Paralysis (NFIP) that succeeded in creating the first safe vaccine against polio. This research, as well as the foundation itself were both encouraged and funded by the U.S. government as a result of the epidemic outbreaks[1] experienced during the late 1940s and early 1950s (Thompson and Duintjer Tebbens, 2006). The fight against the disease entered the national spotlight after the 1932 election of Franklin D. Roosevelt, who was diagnosed with paralytic polio in 1921, to the Presidency. The national sense of urgency to develop a vaccine meant also that the authorities gave a total green light to the researchers, both in terms of funding and other more questionable ethical issues regarding human trials of the Salk vaccine (Baker, 2000). Needless to say Salk's ethical problems would be greatly diminished by the success and safety of his vaccine, but these sort of rushed trials in humans, especially disadvantaged or institutionalized children, would sometimes go awry and result in the infection, and sometimes death, of the subjects of the trials (Mawdsley, 2013). Between 1954 and 1955, a large-scale trial of the vaccine was conducted on more than a million children, with the result being that the Salk vaccine was declared officially safe on April 12, 1955 (Belcher, 1958). The very next day, the NFIP announced it would provide vaccines to be administered to all first and second graders and additional at-risk groups free of charge, and by the month of June 1955 a large-scale vaccination campaign began in the country. Through the signing the Polio Vaccine Assistance Act, President Eisenhower ensured the campaign counted with a large support network and federal funding, marking the first time the government partook in an immunization campaign (Roush et al., 2007; Smith, Wood, & Darden, 2011). By some estimates, around August 1957, a mere two months into the vaccination campaign, around 53% of the population under 40 had received one injection, with 30% receiving three injections as recommended (Sirken, 1962). Within five years of mass vaccination, the reported cases of polio had dropped by an astounding 90%, placing the United States in the path of eradication, which culminated in 1979 (de Quadros, Andrus, Olive, de Macedo, & Henderson, 1992; van Panhuis et al., 2013; Yogev & Edwards, 1999).

Table 1
Countries included in the study, with dates for vaccine introduction and last indigenous case reported.

Country	Vaccine Introduction	Last case reported	*N*
United States	1955	1979	2,210
Denmark	1955	1976	3,910
Finland	1957	1964	9,571
Sweden	1957	1966	66,070
Norway	1957	1969	3,764
Yugoslavia	1961	1996	7,508
Chile	1961	1975	6,996
Federal Republic of Germany	1962	1990	3,149
Greece	1964	1982	3,879
Italy	1964	1983	1,492

Note: Vaccine Introduction refers to the date in which the country experienced its first mass vaccination campaign, as opposed to small or local trails of the vaccine. Last case reported refers to the last case of polio that was attributed to an indigenous wild poliovirus, as opposed to cases where the virus was imported from high-risk regions.

Denmark was, by the time the Salk vaccine was developed and approved, in a very similar situation as that of the United States. Having experienced severe outbreaks of polio in both 1952 and 1953, public health officials were doing great efforts to find a solution to the epidemic at home, as well as following closely the American team research (Hamtoft, 1954; Trubuhovich, 2004). Following the approval of the Salk vaccine as safe in the U.S., the Danish Minister for the Interior made a public announcement on May 24, 1955, regarding the start of an immunization campaign for Danish children using a limited supply of the imported, and much coveted, Salk vaccine (Plesner & Rønne, 1995). The initial campaign covered the population most at-risk, that of children up to grade 5 of elementary school, but as soon as the Danish laboratories could manufacture their own version of the vaccine, the campaign expanded considerably to cover the entire population, who was very eager to get immunized, due to recent epidemics, and participated actively in the public health efforts, which led to a decrease of over 90% in the registered cases of the disease immediately after the immunization campaign (Blume & Geesink, 2000; Böttiger, 1993; Plesner & Rønne, 1995).

The responses of Sweden, Finland, and Norway all happened shortly after Denmark, in the year of 1957. In Sweden, the government attempted at securing stock of the Salk vaccine manufactured in the U.S. to begin a vaccination campaign. However, due to the high demand for the vaccine, as well as some safety accidents because of flawed and rushed American vaccine manufacture,[2] the authorities didn't actually began the immunization until 1957, when they secured stocks of both the Salk vaccine and of their own locally-produced vaccine at the National Bacteriological Laboratory in Stockholm (Fagraeus & Böttiger, 1980; Wesslén, Lycke, Gard, & Olin, 1957). After the first year of the campaign, Sweden stopped using the American imported vaccine and has used only the Swedish version ever since. The mass immunization campaigned is described as being nearly universal in reaching the population, and it took less than ten years for the disease to disappear from the country (Fagraeus & Böttiger, 1980).

Norway, on the other hand, had severe epidemic outbreaks during the years of 1950 and 1954 (with over 4,000 paralytic cases or over 800,000 infections each outbreak), which meant the public opinion was eager to have access to a vaccine and participate in immunization (Harthug, 2014; Rekand et al., 2003). The government, through the Nordic Committee for Polio, secured small amounts of the Salk vaccine from the US and started small immunization trials as early as October 1956 (Aase et al., 2015; Druglitrø and Kirk, 2014). It wasn't until the spring of 1957 that enough vaccines were secured in order to launch a mass vaccination campaign, which included posters and public announcements via NRK, the national radio service (Folkehelseinstittutet, 2018b; Mellbye, 1959). Approximately 500,000 schoolchildren were vaccinated with two doses by the end of the spring of 1957 (Lobben, 2001). Successively, as availability improved, youth and adults under 40 were also offered the vaccine free of charge. Norway ended up eradicating the disease 13 years after introducing the Salk vaccine (Aase et al., 2015; Folkehelseinstittutet, 2018a).

In Finland, following the outbreaks of polio in 1954 and 1956 (which each left around 800 paralytic cases as a result of over 160,000 infections), the vaccine was first introduced in 1957, with the campaign planning on giving each individual up to six injections from infancy to ages 16–17 (Hovi et al., 1986; Lapinleimu, 1984; Murdin, Barreto, &

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[1] Between 1950 and 1954, epidemics all over the country caused an incidence rate of paralytic polio of around 14.6 cases per 100,000 inhabitants (or well over 20,000 cases, which means the total infections were around 4 million), with the epidemic centre shifting from the northeast, to the west, then finally covering all the territory (Trevelyan, Smallman-Raynor, & Cliff, 2005).

[2] After the Salk vaccine was declared safe, several laboratories applied for licenses to manufacture the vaccine in order to satisfy the increasing demand for it. One of these, the Cutler Laboratories in California, produced vaccines using a defective method that did not inactivate (or kill) the virus appropriately. These vaccines were applied to 200,000 children, and were proven to cause over 40,000 cases of polio, of which 200 resulted in paralysis and 10 were fatal (Fitzpatrick, 2006). The Cutler incident, as was known at the time, greatly damaged the reputation of, and trust in, the Salk vaccine.

Plotkin, 1996). Even if the campaign began in 1957, the national infrastructure for routine mass-vaccination was not put in place until 1960, and therefore, initial immunization was rather low, compared to other Nordic countries. By the end of 1961, however, more than half the population was vaccinated, with 1,5 million people having received three doses of the vaccine. The last case of polio from an indigenous poliovirus occurred in 1964 (Bonnet & Dutta, 2008; Lapinleimu & Stenvik, 1981).

The next country in the sample to introduce vaccination was the Socialist Federal Republic of Yugoslavia (henceforth Yugoslavia), which unlike the other countries in this study, was a confederation of six nations (Serbia[3] Montenegro, Croatia, Slovenia, Macedonia, and Bosnia-Herzegovina) under one communist government led by Josip Broz Tito (Žižmond, 1992). Due to the multinational nature of Yugoslavia, epidemics and strategies in response varied nation by nation, with those most affected (Croatia and Slovenia) also being the first to act and launch small immunization campaigns (Zupancic-Kmet, 1961). It wasn't until 1961 when the federal government launched a federation-wide mass vaccination campaign using a vaccine produced locally at the Institute of Immunology of Zagreb and the Institute of Hygiene in Belgrade (Melnick, 1962; Plotkin, 1971). The decentralization of government within the federation, as well as differences in endemic and epidemic incidence rates, meant however that the vaccination campaign was not uniformly implemented and therefore lacked the efficacy of other nations' similar efforts (Trajkov, Angelova, Krteva, & Datsev, 1978). The failure to completely eradicate the virus meant the disease kept coming back regularly in small outbreaks, which were exacerbated by the political instability caused by the wars that led to the disintegration of Yugoslavia in the early 1990s (Patriarca, Sutter, & Oostvogel, 1997). It wasn't until after stability returned to the region that poliovirus would be finally eradicated from the area in 1996.

Chile, unlike the other countries mentioned previously, managed to get rid of polio using mainly the oral polio vaccine (OPV), developed by Albert Sabin in 1961, instead of the Salk Vaccine. In fact, Sabin himself traveled to the country to advise on the planning and implementation of the mass vaccination campaign launched there as soon as the OPV was declared safe (Sabin, 1962b). The campaign aimed to vaccinate 80% of all children aged three months to seven years (Banfi, 1975). During the campaign, over 2.5 million children received the OPV, and within a period of 15 days after launching the campaign, weekly infections were reduced by 72%. Another two weeks later, they had been decreased by 90% (Laval, 2007). The Chilean campaign was extremely successful partly because by 1961 well over 80% of all births happened in a hospital, which facilitated immunization after birth and also to the fact that the country was just coming out of a severe outbreak of polio in the same year of the vaccine introduction, which predisposed parents to allow their children to be immunized as early as possible (Banfi et al., 1974). The efforts in the campaign led to eradication of polio in Chile by 1975 (Laval, 2007).

Germany at the time was split into two parts, the Federal Republic of Germany (FRG) in the West, and the Soviet-run German Democratic Republic (GDR) in the east. Vaccination was, of all things, influenced more by a competitive spirit between the two parts than by actual concerns for public health. Unlike many other western nations, the FRG did not implement the Salk injected vaccine immediately after its discovery in 1955. Among the main reasons were dislike for injections among the population, distrust in American-produced vaccines, and the false belief that the German poliovirus was not as aggressive as the American one and therefore the public did not need a vaccine (Windorfer & Feil, 2000; Lindner & Blume, 2006). After countries in Western

Europe began using the vaccine in 1955–1957, some federal states[4] started small vaccination campaigns that were both uncoordinated and insufficient to guarantee herd immunity (Lindner & Blume, 2006). In 1960, the GDR launched a vaccination campaign using the Sabin vaccine. Since the OPV contains live virus, people not vaccinated are at risk of infection from those who are immunized, and so this campaign was done swiftly and prompted rapid action from the FRG to also immunize the inhabitants of West Berlin, who were at risk of contracting it from vaccinated East Germans (Lennartz & Valenciano, 1961). After the last polio outbreak in the FRG in 1961 (800,000 infections, over 4,000 paralytic cases), and under pressure to match the success of the GDR campaign, the government launched a nationwide immunization campaign using also the OPV (Feil, Windorfer, Diedrich, & Schreier, 2000; Windorfer & Feil, 2000). The mass vaccination was a success[5]: 23 million people were vaccinated during 1962, but even though the vaccine drastically diminished the risk of epidemic infections, the country saw sporadic cases surge across the states, with the last reported case of polio in Germany occurring in 1990 (Windorfer & Feil, 2000).

Greece experienced regular outbreaks of polio all through the 1950s, but political instability in the country prevented a large-scale response. It wasn't until 1962 that the first doses of the Salk vaccine were administered in Greece, and not until 1964, this time using the Sabin oral vaccine, that a mass immunization campaign was launched in the country (Frantzidou-Adamopoulou, 1992). The campaign was at the time the largest vaccination effort the country had seen, with some 2.7 million children (ages 3 months to 18 years) received the immunization (Papaemmanuel, 1965). Despite large disparities in infrastructure between rural and urban areas of the country, studies have found no differences between the two, nor between genders, when it comes to vaccination rates (Lionis, Chatziarsenis, Antonakis, Gianoulis, & Fioretos, 1998; Pavlatou, Triantaphylli, & Katsilambrou-Varonou, 1965). While the indigenous virus was eradicated in 1982, some settlements of Romani people experienced an outbreak that could be traced back to infections in neighboring Albania (Ciofi Degli Atti et al., 1997; Fiore et al., 1998; Frantzidou, Diza, Halkia, & Antoniadis, 2005).

Italy, like was the case with Germany, had an initial attempt at introducing the Salk vaccine during 1957, using a version manufactured in the country, but the disorganized nature and limited coverage of the campaign, as well as some defects with the manufacture of the vaccine,[6] meant that the country was not protected against the disease which struck hard during 1958 (approx. 1.6 million infections, 8,377 paralytic cases), being the worst outbreak Italy would face (Crovari, 2012; Giovanardi, 1969). In response to this, the Italian government decided to change tactics and manufacture the recently released Sabin oral vaccine, which after being declared safe and effective was used for a mass immunization campaign during March–October 1964. The campaign was extremely well planned and successful in coverage, reaching up to 90% of children between six months and fourteen years of age (Crovari, 2012). Following the campaign, cases would decrease by 99% within four years, and the last indigenous reported case occurred in 1983 (Giovanardi, 1969).

Across the countries in the sample, two patterns are observed, a first reaction driven by the most recent epidemics, in which a trial or test was implemented followed by mass, coordinated, and government-led

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[3] Two autonomous provinces, Kosovo and Vojvodina, were subordinated to Serbia.

[4] 10 federal states or *bundesländer* formed the Federal Republic of Germany and had a lot of autonomy when it came to public policy including healthcare.

[5] To make it attractive to the people, it was given with a sugar lump using the slogan *"Schluckimpfung ist süß, Kinderlhmung ist grausam"* which translates into "oral vaccination is sweet, infantile paralysis is horrible"(Windorfer & Feil, 2000).

[6] The vaccine manufactured by Italian laboratories proved to have too low immunogenicity, the ability of a vaccine to generate a immune response in the body and therefore create antibodies, which rendered the vaccine ineffective and granted little to no protection (Crovari, 2012).

immunization campaign. In most of these cases, implementation of mass immunization led to eradication within a few years, with some exceptions being made due to geopolitical conflicts, which severely weakens a state's ability to coordinate public policy.

3. Related literature

This study is related to two main branches of literature. Firstly, research has shown that conditions in early-life have a particularly important role in the development of adult health (Barker, 1990) and later-life capabilities, including the accumulation of human capital (Cunha & Heckman, 2007). In this framework, early-life adversities are reflected in diminished early-life health, which would impact adult health and, therefore, economic outcomes such as labor productivity (Almond et al., 2018). Disease load in early-life is considered to be one of the aspects that can have a lasting impact on children's outcomes, and so research has looked for signs of long-term effects (often referred to as *scarring*) of diseases, and has found them on a variety of health and economic outcomes like height (Karimi & Basu, 2018), cognitive, abilities (Case & Paxson, 2009; Chay, Guryan, & Mazumder, 2009), years of education (Almond, 2006; Bundervoet & Fransen, 2018; Cunha, Heckman, & Schennach, 2010), income (Bleakley, 2007; Lazuka, 2020), and socioeconomic status (Bengtsson & Mineau, 2009; Quaranta, 2013).

Secondly, there is an increasing number of studies that attempt to evaluate public interventions that aim at improving the conditions experienced during early-life, especially when it comes to disease load. For instance, Bleakley (2007) found that eradicating hookworm disease had lasting impact on adult income and increased the returns to schooling among people in the American south. Bleakley (2010) showed similarly that malaria-eradication campaigns in Latin American countries led to income gains for the cohorts that were born after eradication. Lazuka (2018) showed that receiving treatment from qualified midwives at birth led to reduced neonatal as well as adult mortality from cardiovascular diseases and diabetes. Lazuka (2020) found that introduction of sulphonamide antibiotics in Sweden as treatment for pneumonia led to a reduction in the disease load experienced by children that would later be reflected in higher incomes during adulthood. Currie and Rossin-Slater (2015) review several interventions aimed at improving early-life conditions, finding that some of the most effective programs are those that target infant and childhood health.

For the particular case of the long-term effects of polio, two recent studies have focused on the experience of Scandinavian countries. Gensowski, Nielsen, Nielsen, Rossin-Slater, and Wüst (2019) explored the effect of the last polio epidemic in Denmark on individual's long-term outcomes (education, occupation, and health). They find that, for the Danish case, paralytic polio survivors obtain a higher education and are more likely to work in white-collar occupations than the non-paralytic survivors, speaking of a sort of "compensatory behaviour". For the Swedish case, Serratos-Sotelo et al. (2019) found that the introduction of the vaccine against polio in 1957 had no economically significant long-term effects on native Swedish children's adult income, educational attainment, or hospitalizations. They attribute these lack of impact to the pathological characteristics of the disease, presenting evidence that polio epidemics did not scar children like other diseases' did.

4. Data

The main source of data for this study was the Swedish Longitudinal

Immigrant Database (SLI), hosted at the Centre for Economic Demography at Lund University. The SLI is a unique database which contains economic and demographic register data for a randomly-selected representative sample of individuals from both Sweden and other 16 countries of origin.[7] Because of its longitudinal nature, the SLI allows for an individual year-to-year follow up in areas such as income and education from 1968 to 2001, and health-related outcomes from 1987 to 2003. However, due to the structure of the data, it is not possible to observe date of arrival to Sweden for those who migrated before 1968, which affects most of our studied cohorts. This presents a problem since it would not be possible to differentiate, for instance, someone born abroad who moved to Sweden in their third year of life from someone who did that in their tenth year, with their exposures to disease environments being completely different. In order to circumvent this issue, this study uses only data on year of birth, since it is reasonable to assume that individuals born abroad experienced the early-life environment of their country of origin at least during their year of birth. This is an important difference with the analysis carried out in Serratos-Sotelo et al. (2019), where the authors looked at children aged 0–10. While it would've been ideal to include the same age-span here, the data limitations above described impeded the so doing. Summary statistics for the variables included in this study are presented in Table 2.

For this paper, four outcomes were selected and calculated from the data. The first one is the natural logarithm of the average income between the ages of 30 and 35. The average over five years allows us to observe a smoother behaviour of income that is not completely dependant on yearly or sudden shocks. While it would've been preferred to use a longer period of time to observe income in adulthood, say ages 35 to 45, the current 5-year average was the best option due to the cohorts included and the last observable date in the income registers (2001).

The second outcome is the total years of schooling for each individual. This was calculated using the information on highest degree obtained from the educational register and the method described in Antelius and Björklund (2000) for a transformation into average years of education that accounts for slight differences in the length of educational levels below the highest degree obtained (e.g. different lengths of elementary and high school for college graduates).

The third and fourth outcomes relate to long-term health. A measure of the total number of hospitalizations an individual had during the

Table 2
Summary statistics.

	Mean	(Std. Dev.)	Min.	Max.	N
Exposure	0.55	(0.49)	0	1	108,549
ln (Average Income 30–35)	11.19	(1.00)	2.36	15.08	80,448
Years of Schooling	11.89	(2.66)	6	19	108,549
Total Days of Hospitalization	22.13	(104.65)	0	6354	66,927
Total Number of Hospitalizations	3.73	(5.81)	1	257	66,927
Female	0.51	(0.49)	0	1	108,549
Ever Married	0.76	(0.42)	0	1	108,549
Year of Birth	1958.73	(7.38)	1946	1971	108,549
Year of Vaccine Introduction	1957.91	(2.16)	1955	1964	108,549

Source: Author's elaboration with data from the Swedish Longitudinal Immigrant Database (SLI).

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[7] This is a great advantage of the SLI over the regular Swedish registers, since the latter usually group countries of origin to protect the anonymity of smaller groups, e,g, "South America" instead of "Chile". Since the identification strategy for this paper rests on information on vaccine introduction at the country-of-origin level, the specificity of the SLI was vital.

years observable in the inpatient register (1987–2003) was calculated. Furthermore, another aspect of hospitalization-related health was captured by calculating the total number of days an individual was hospitalized according to the register. These two measures give a somewhat similar but complementary picture of adult health, since focusing on total number of hospitalizations allows us to observe those who required repeated medical attention, while days of hospitalization provide a picture of how time intensive the care was, regardless of admissions and discharges.

5. Methodological approach

While this study is expanding on the results from Serratos-Sotelo et al. (2019), the methodological approach followed here differs to accommodate for data restrictions, as well as the implementation of the vaccine in this international setting. Since the vaccine against polio was introduced in each of the countries included in the sample at a different date (see Table 1), a differences-in-differences (DiD) model can be utilized. One of the main assumptions here is that the time difference in vaccine introduction can be considered to be plausibly exogenous, since the main limitation for its application was, first, the nonexistence of the vaccine, and second, the limited supply due to manufacturing which failed to meet global demand. The other main assumption of the DiD model is the existence of pre-treatment parallel trends in outcomes among the treated and untreated groups. Appendix 1 shows graphical evidence that supports the hypothesis that this assumption holds in this analysis. In this setting, it is precisely the time variation across countries that is exploited to estimate the causal effect of exposure, and the model specified is as follows:

$$Y_{ict} = \beta_0 + \beta_1 \cdot Exposure_{ct} + \delta_c + \delta_t + \gamma X_{ict} + \phi_{ct} + \varepsilon_{ict} \tag{1}$$

where Y_{ict} is any of the adult outcomes of interest (income, education, health), $Exposure_{ct}$ is an indicator variable that takes the value of 1 if the individual i was exposed to the vaccine against polio during their year of birth t at their country of origin c and 0 otherwise. Fixed effects for country of origin and year of birth are labeled δ_c and δ_t. X_{ict} is a vector of controls at the individual level, ϕ_{ct} is a set of country-specific linear trends, and ε_{ict} is the error term.

The models presented in the next section include controls for individual's gender (51% of the sample is female) and an indicator for civil status that takes the value of 1 if the individual was ever married, and 0 if they remained single throughout the observation period. They also control for GDP per capita in the year and country of birth.[8]

6. Results

In this section the results from the estimation of the models specified in Equation (1) are presented. Table 3 presents the results from the regressions of the effect of exposure to the polio vaccination in the year of birth at the country of origin on adult income, educational achievement, and hospitalizations. Two models are fitted for each outcome, one with and one without the vector of individual controls. All models shown include fixed effects for country of origin and year of birth, as well as country-specific linear trends. Standard errors are clustered at the (country of birth × year of birth) level, to avoid calculations with small number of clusters (Bertrand, Duflo, & Mullainathan, 2004) and accounting for variation at these levels not already explained by the included fixed effects (Cameron & Miller, 2015).

The first panel of Table 3 displays the results for the estimation of the

model presented in Equation (1) using the full sample with individuals from the 10 countries shown in Table 1. These results show non-significant effects of exposure to the vaccine on the outcomes all across the table. In other words, being exposed to the vaccine against polio during the year of birth at the country of origin has no statistically significant impact on later-life outcomes such as adult income, total years of schooling, and number or days of hospitalization, regardless of nationality.

The following panels of Table 3 present the results for specifications ran with a restricted sample. The rationale behind these models is that some countries may be pulling the results towards non-significance. In the second model, native Swedes are excluded for two reasons, they represent a large portion of the full sample, and a previous study showed they exhibited no economic long-term effects from exposure to the polio vaccine (Serratos-Sotelo et al., 2019). As can be seen, excluding native Swedes and focusing only on immigrants does not change the results, which remain insignificant.

Panel 3 follows a similar logic and presents the results of models fitted with a sample that excluded both Native Swedes and Yugoslavians. As was discussed in section 2.2, Yugoslavia can be seen as an outlier of sorts among the countries in the sample. Because of the political and social uniqueness of the region, vaccination failed to eradicate the virus there until 1996 (the latest of any country in the sample), and the constant outbreaks of the disease reveal that the population was not fully protected by the mass vaccination campaign. In this scenario, and because Yugoslavians were the second largest migrant group to Sweden, the models are presented here excluding them to ensure the results are not sensitive. As can be observed, they remain unchanged, showing no significant long-term economic effect of exposure to polio vaccine.

One possible explanation for the lack of long-term benefits from exposure to a disease-preventing vaccine is that put forward by Serratos-Sotelo et al. (2019), in their study of polio among native Swedes, they find no evidence of scarring from exposure to a polio outbreak, which in turn explains why removing the risk of infection via vaccines, while enormously beneficial in the short run, had no noticeable long-term economic effects on those exposed to it. Table 4 presents the results from a similar scarring analysis. In this setting, information on the last epidemic outbreak of polio in each country in the sample is used. Epidemic outbreaks, by definition an unusual deviation from the incidence rate trend of any disease, have been used in the literature as natural experiments to examine long-term effects of disease environment exposures during early-life, comparing those exposed to those who by their time of birth avoided the same exposure.[9] In this particular case, exposure is defined as being born in the year where the last major epidemic of polio was registered in the country of origin. I compare the outcomes of those exposed to a group of non-exposed infants born either the year immediately preceding or following the last registered epidemic outbreak.[10]

Table 4 shows that there were no noticeable scarring effects from exposure to a polio epidemic in our sample of individuals from 10 different countries. None of our estimations for long-term effects on our four selected outcomes returned any statistically significant coefficient, which provides support for the hypothesis put forward earlier that the

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[8] I use the real GDP per capita in 2011 US dollars for each country obtained from the Madisson Project Database 2018 (Bolt, Inklaar, de Jong, & Zanden,). The data was available for all countries and all years, with the exception for Yugoslavia in 1946.

[9] for examples of scarring analysis for several diseases, see Myrskylä et al. (2013); Almond (2006); Quaranta (2013).

[10] For each country, data was gathered on when the last major outbreak before vaccine introduction happened, this time was defined as time t, the exposed group are those born in year t, while the non-exposed control group is comprised of those individuals born in years $t − 1$ and $t + 1$ (using only those born in $t + 1$ did not change the results). Since year t is different for every country, I control for birth cohort and country fixed effects. This definition of exposure is therefore congruent and comparable to the results from the main analysis, since exposure only in the year of birth is the main criteria for categorization.

Table 3
The effect of exposure to the polio vaccine in the year and country of birth on adult outcomes.

	Adult Income		Educational Achievement		Hospitalizations			
	ln (Avg. Income 30–35)		Years of Schooling		Days of Hospit.		Number of Hospit.	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
				Full Sample				
Exposure	0.0514	0.0077	0.0146	0.0664	0.0513	0.567	0.0861	0.077
	(0.0276)	(0.0278)	(0.0630)	(0.0647)	(2.115)	(2.457)	(0.0902)	(0.1026)
Controls	No	Yes	No	Yes	No	Yes	No	Yes
N	80,264	80,264	108,315	108,315	66,790	66,790	66,790	66,790
adj. R^2	0.111	0.192	0.065	0.065	0.002	0.006	0.004	0.016
				Subsample 1: Excluding Swedes				
Exposure	0.0361	0.0079	0.0715	0.1093	0.247	1.781	0.131	0.133
	(0.0337)	(0.0325)	(0.0711)	(0.0736)	(2.503)	(2.612)	(0.134)	(0.141)
Controls	No	Yes	No	Yes	No	Yes	No	Yes
N	29,469	29,469	42,245	42,245	23,854	23,854	23,854	23,854
adj. R^2	0.049	0.093	0.098	0.099	0.003	0.009	0.012	0.020
				Subsample 2: Excluding Swedes and Yugoslavians				
Exposure	0.0600	0.0332	0.0527	0.0816	−0.553	−0.669	0.117	0.0964
	(0.0387)	(0.0364)	(0.0849)	(0.0865)	(2.737)	(2.848)	(0.131)	(0.139)
Controls	No	Yes	No	Yes	No	Yes	No	Yes
N	24,217	24,217	34,971	34,971	19,493	19,493	19,493	19,493
adj. R^2	0.057	0.109	0.100	0.100	0.004	0.010	0.013	0.022

*$p<0.05$, **$p<0.01$.***$p<0.001$
Standard errors, clustered at the Country of Birth x Year of Birth level, in parentheses. All models shown control for Country-specific linear trends and Country-of-Birth and Year-of-Birth Fixed Effects. Where indicated, the models control also for the individuals' sex, civil status, years of education (as long as this is not the outcome), and real GDP per capita (in 2011 USD) in the year and country of birth.
Source: Author's calculations with data from the Swedish Longitudinal Immigrant Database (SLI) and the Madisson Project Database 2018.

Table 4
Scarring Effects of Polio Exposure. Comparison of cohorts born immediately before and after the last Epidemic Polio Outbreak in the country of origin.

	Adult Income	Educational Achievement	Hospitalizations	
	ln(Avg. Income 30–35)	Years of Schooling	Days of Hospit.	Number of Hospit.
	(1)	(2)	(3)	(4)
Scarring effect	0.0833	0.126	4.804	0.0321
	(0.0707)	(.113879)	(6.093)	(.0851)
N	11,517	12,405	7,298	7,298
adj. R^2	0.1103	0.0617	0.0083	0.0124

*$p<0.05$, **$p<0.01$.***$p<0.001$
Standard errors, clustered at the Country of Birth x Year of Birth level, in parentheses. All models shown control for Country-of-Birth and Year-of-Birth Fixed Effects, the individuals' sex, civil status, years of education (as long as this is not the outcome), and real GDP per capita (in 2011 USD) in the year and country of birth.
Source: Author's calculations with data from the Swedish Longitudinal Immigrant Database (SLI) and the Madisson Project Database 2018.

lack of effect from exposure to the vaccine is related to the lack of scarring effects from the disease.

7. Conclusion

This paper seeks to explore if there were any long-term economic effects of exposure in early-life to the vaccine against polio on later-life outcomes. Using a longitudinal database with individuals from 10 different countries, I employ a DiD methodology to estimate the causal effect of said exposure. The results seem to support the findings of Serratos-Sotelo et al. (2019), in that the exposure to the vaccine appears to have no long-term impact on adult outcomes, in this case regardless of national origin. The scarring analysis carried out also pointed towards no noticeable scarring effects from exposure to a polio epidemic, which might help explain why the vaccine appears to have had no long-term impact on adult outcomes[11].

The vaccine helped eradicate the disease from all the studied countries and its efficacy was never in question during this study, however the findings here do shed some interesting light on issues of scarring. A variety of studies have found long-term effects of exposure to illness, commonly referred to as scarring (Almond, 2006; Almond et al., 2018;

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[11] Another possibility that would explain the lack of scarring, which was beyond the scope of this paper, is that the Swedish context, with well-developed and equally-accessible systems of healthcare and education, has a positive effect on the lives of all its inhabitants, both native and immigrants, regardless of vaccination or infection status. In this scenario, negative shocks would be countered by the positive effect of access to welfare systems, giving the appearance that no negative shock existed in the first place. While this is not a likely scenario, given that research has already found in this context scarring/ long-term effects of exposures to different diseases and health interventions (Helgertz & Bengtsson, 2019; Lazuka, 2020; Quaranta, 2013), completely ruling out this possibility would require further research, especially studies with access to multiple national administrative data, in which the same disease outbreak would be studied, comparing natives and migrants in several countries over a similar period of time.

Myrskylä, Mehta, & Chang, 2013; Quaranta, 2013), and lots more have found beneficial effects of preventing this exposure through medical innovations. The present study presents evidence that this is not a universal case for every disease and every medical breakthrough, but that, as in the case of polio, lots of aspects need to be taken into consideration, especially the epidemiology and pathology of the disease, in order to assess whether or not long-term effects are to be found. The analysis of polio strongly suggests that scarring and long-term effects are, at the very least, disease-specific and might be affected or even determined by the pathology of each disease and how they affect the human body, opening research possibilities into which diseases scar individuals and which treatments provided long-term economic benefits to those who received them.
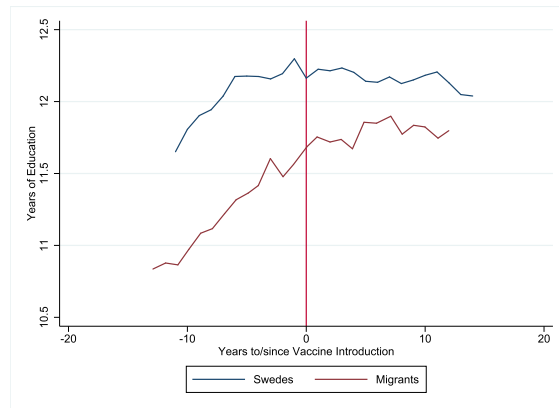
Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ssmph.2020.100589.
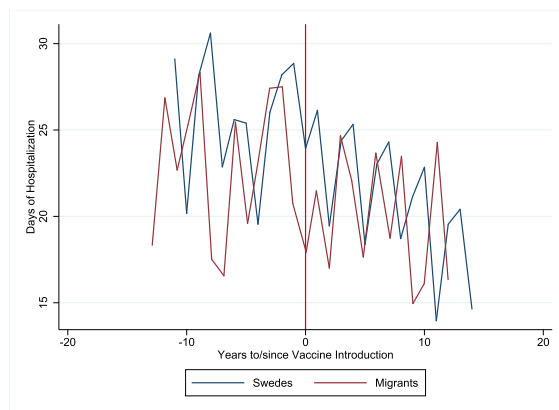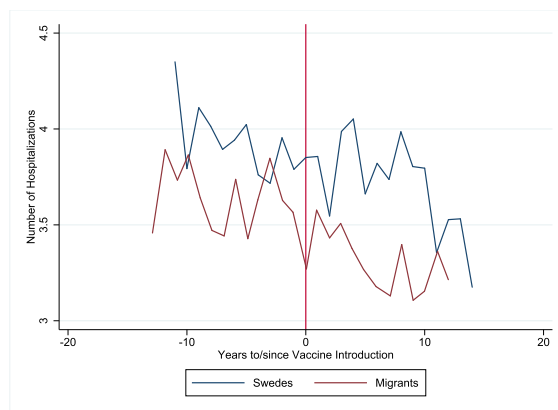
Appendices
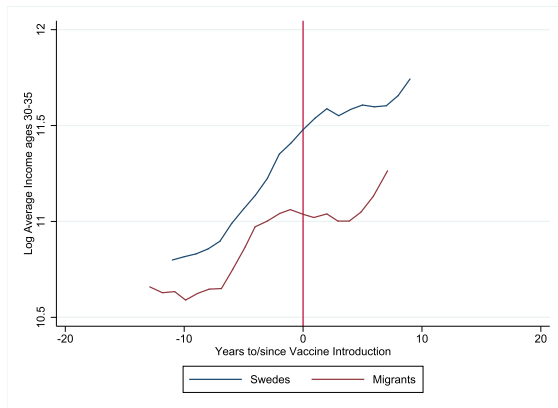
(a) Outcome 1: Log Average Income ages 30-35

(b) Outcome 2: Years of Education

(c) Outcome 3: Days of Hospitalization

(d) Outcome 4: Number of Hospitalizations

Appendix 1. Trends in later-life outcomes for cohorts born before and after the introduction of the vaccine against poliomyelitis in their country of origin, by migration status in Sweden (Swedes/Migrants).

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