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Katharina Muhlhoff,
Universidad Carlos III de Madrid

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Abstract

Without safe and effective vaccination the current coronavirus pandemic will not get under control. Moreover, economic history suggests that even with vaccination, success is uncertain. To make this point, the present paper studies smallpox - an aggressive viral disease like Covid19 - as a model for future coronavirus immunization. Setting out from the formal basis of mathematical epidemiology and the theory of economic externalities, it finds that (i) vaccination externalities are non-monotonous in the burden of disease, that (ii) public interventions need to be tailored to the specific stages of the externality and (iii) that concrete implementation matters as much as formal institutions. To derive practical implications from these results, I retrace the prevention policies of two German states, Baden and Wurttemberg, which provide an intriguing natural experiment: Both featured similar socio-economic characteristics, both were initially ridden by smallpox and both passed mandatory vaccination laws at roughly the same time. But whereas laws hardly differed, one state - Baden - performed better in terms of epidemiological outcomes (smallpox prevalence and mortality), in cost efficiency and in measures of compliance. The main reasons for this success were the rapid implementation of mass vaccination, central coordination of vaccine supply, supervision and positive incentives for medical professionals. The bottom line of the historical case is therefore that governments which invest early in the infrastructural and personnel needs of a mass-vaccination system are likely rewarded by high popular acceptance and low disease prevalence.

JEL Codes: I12, I18, I38, N33, N43

Keywords: Health Externalities, Vaccination, Smallpox, Vaccine Resistance, Government Regulation, Historical Public Health Institutions

[1] Corresponding Author: Katharina Muhlhoff (kmuhlhof@clio.uc3m.es)

1. Introduction:

When the first wave of the coronavirus pandemic abated, deserted city centers returned to their usual hustle and bustle. It seemed as if the worst was over, but this optimism was grossly mistaken. In autumn 2020 the virus returned with the same fury as in spring, mocking all efforts to contain its spread and leaving us with the bleak perspective that without safe and effective mass vaccination, chances to end the pandemic are minimal. And even if clinical trials of new vaccines yielded rapid success, the race against SARS-Cov-2 will probably be a matter of years rather than months.

In fact, the only disease which was eliminated by vaccination was smallpox and reaching this aim took almost two centuries. Interestingly, winning the battle against smallpox did not take so long because the original vaccine had been deficient or because the virus mutated too rapidly (Henderson, (1987), pp. 536). What allowed smallpox to survive 200 years into the era of vaccination were not *medical* but *socio-economic* problems: The divergence between private and socially optimal levels of immunization and the inefficient implementation of the prevention policies. Accordingly, all the problems which trouble today's health planners - organizing comprehensive vaccination campaigns, securing the support of the medical profession or providing for the constant supply of high quality vaccine - existed already in the first decades the 19th century. To avoid that the coronavirus stays with us for the next 200 years, we are therefore well advised to study the institutional arrangements which ultimately allowed us to eradicate one of the deadliest epidemic diseases in human history.

Obviously, the analysis of smallpox is only meaningful for the current pandemic if one studies formal and informal institutions in sufficient detail. Since such a high resolution is unfeasible for a big cross-section of countries, I will eexclusively focus on the case of Baden and Wurttemberg, two states in the South West of the German Confederation. The choice of the two countries is motivated by the following considerations: First, unlike the big European nation states France, Prussia, England or Spain, Baden and Wurttemberg were among the first to pass vaccination legislation and made smallpox prevention a matter of "public health policy" at the beginning of the 19th century.[1] As a result, the two allow us to retrace successful and failed institutional experiments from the point in time when vaccination became first available - the current state of the Covid19 epidemic - to the time when smallpox had almost disappeared from collective consciousness. Besides this, the two states offer an almost ideal

[1] The others did not do so before the second half of the 19th century.

experimental set-up because (i) they adopted similar laws but different implementation strategies, because they (ii) resembled each other in terms of social and economic background conditions[2] and because (iii) they were located in a region which resembled today's globalized world due to its extensive trade and (labor-)mobility.

As it steps back into the history of smallpox in Germany, the present paper contributes long-run evidence to the current discussion of optimal anti Covid19 strategies. Knowing about the historical record of prevention policies is fundamental because at the peak of an epidemic collective fear tends to hide the social and economic obstacles to mass vaccination. Yet, eventually adverse incentives will manifest and the German case illustrates that seemingly minor details in the implementation and popular communication are strong enough to jeopardize the ultimate success of immunization. Besides informing ongoing policy design, the focus on individual decisions and informal institutions adds new insights to various strands of literature in economics, history and sociology. For, as section 2 flashes out in detail, past research debates have been dominated by „big issues" like the general theory of prevention externalities or comparisons of different countries at the national level. What this big picture is missing are small questions which still might be crucial: „Why do some people resist sanitary precautions and oppose vaccination?“, „How will individual agents react once successful policies reduce disease incidence?“ and „What is needed to keep the prevention system running without overstraining local budgets and human resources?“

The following sections attempt to provide answers to these questions. Section 2 discusses related literature and section 3 provides basic knowledge of the historical epidemiology of smallpox. This done, section 4 introduces the structural framework mathematical epidemiology we need to relate the course of an epidemic and the incentives of individuals and governments. Sections 5 and 6 apply this methodology to the historical case of Baden and Wurttemberg and identify parallels and policy implications for the Covid19 pandemic. Finally, section 7 concludes.

2. Related Literature:

To begin with, since vaccination and the “herd immunity" it creates are prime examples of public goods, economic theorists have studied them extensively. However, the interest and methodology of this research differ substantially from mine. In particular, the central debate in public and political economics is, whether or not decentralized (i.e. non-mandatory)

[2] See appendix for a rough overview of socio-political indicators

vaccination yields socially optimal immunization rates. The conditions under which decentralization externalities do or do not prevent welfare maximizing vaccination have been scrutinized in the papers of Brito et al. (1991), Francis (1997), Gersovitz (2003, 2011) and Gersovitz and Hammer (2004). Yet, although the categorical question „mandatory or not“ is discussed under a great range of assumptions - including sophisticated epidemic dynamics, sequential policy choice, differentiated medical treatment and prevention or heterogeneous preferences[3] - this literature largely ignores the possibility that measures which maximize social welfare in *theory* might fail to do so in *practice*. The need to study the consequences of concrete implementation strategies is recognized in recent papers by Abertman (2011), and Bethune and Korinek (2020). Yet, due to their focus on current health policies, the empirical findings of these contributions are necessarily limited to the instantaneous effect of epidemiological interventions. This lacuna is not completely filled by scholars in social and medical history. For, although Baldwin (2001), Sköld (1996) and Rigau-Pérez (1989) just as authors of recent empirical field studies like Feilden (1998), Gauri (2002), Bonu et al. (2003), or Quaiyum et al. (1997) have been careful to view the long-term success of epidemiological interventions as the result of a continuous political effort, their work too is mostly concerned with the macro level of entire countries. And whereas Baldwin (2001) and Troesken (2015) present compelling evidence about the correlation between a country's political framework and its propensity to opt for mandatory or liberal vaccination policies, they hardly discuss why countries with similar laws may still experience mixed immunization success.

By contrast, the importance of communication and organizational aspects of prevention has been discussed in the burgeoning literature on vaccine resistance. This area resembles authors from diverse backgrounds including sociology, psychology and history who study anti vaccination movements in different countries and historical settings. Where empirical results are concerned, authors like Aharon et al. (2017) or Meyer and Reiter (2004) point to the importance of disseminating information to minorities and socially disadvantaged groups. A second result of this literature is that vaccine hesitancy is - somewhat paradoxically - widespread in well-informed, wealthy, socially connected and communicative groups Finally, in experimental settings, Verelst et al. (2018) and Lim and Zhang (2020) observe that high vaccination uptake is feasible if vaccination is perceived as effective, accessible, safe and tailored to the level of disease prevalence.

[3] For examples see: Boulier et al. (2007); Ward (2014); Althouse et al. (2010); Reluga et al. (2010); Chen and Toxvaerd (2014)

How these requirements can be met by actual policies is an open question. To contribute insights from long-term evidence to this discussion, the next section sketches the history of the old disease - smallpox - to demonstrate that its economic impact was comparable with the damage caused by SARS-Cov 2. Moreover, the historical overview will show that the battle against smallpox followed a characteristic chronology which was driven by economic incentives. Understanding and anticipating this order of events will arguably help to design efficient responses for the current pandemic.

3. Historical Epidemiology of Smallpox:

Unlike SARS-Cov2, smallpox had not recently emerged in the period we are studying. In fact, the disease had been endemic in Europe since the 13th century. Nevertheless, there are noticeable parallels between smallpox and the coronavirus epidemic because the introduction of the cowpox vaccination provided – for the first time in history! – an effective means to prevent (albeit not to treat) smallpox. Hence, the 19th century is a turning point in the history of smallpox at which governments and individuals embarked on a trial-and-error process to find optimal preventive strategies. Besides the similar socio-political setup, Covid19 and smallpox share important epidemiological characteristics. First, smallpox just as SARS-Cov-2 is an air bone, highly contagious viral disease which spreads mainly via droplet infection. Second, incubation times and the infective spell are similar and round 8 days which leads to comparable dynamic patterns.[4] Finally, if anything, smallpox was as widespread as SARS-Cov-2: The number of persons who contracted the disease at some point of their lives was so overwhelming that 18th century scholars pointed out that no-one would make a difference between smallpox and the plague, if there had not been the habit to count children's lives only once they had survived the former.[5] In the 19th century scholars called them the "communist disease" which struck rich and poor with regardless of class, sex or mode of living (Bohn (1875), p.1). The picture is confirmed by the sparse set of original epidemiological data: Swedish and French censuses indicate that smallpox accounted for roughly 11% of overall mortality and various German states reported shares between 11% (Berlin, 1754-1800), 12.5% (Eastern Prussia, 1765-1785) and 11% (Wurttemberg, 1750-1800).[6] Concerning morbidity, historical sources are even gloomier since statisticians from France and Germany

[4] See WHO coronavirus factsheet: https://www.who.int/health-topics/coronavirus#tab=tab_3
[5] Extensive historical descriptions of smallpox can be found in: Christian August Struve, Anleitung zur Kenntnis und Impfung der Kuhpocken, Breslau 1802, pp. 1-2; Peter Baldwin, Contagion and the State, Cambridge 1999, p. 244
[6] All Data from Paul Kübler, Geschichte der Pocken und der Impfung, Berlin 1901, chapter 4

estimated that 80% of each cohort got infected – a number which present-day studies only slightly corrected to 66-75% (Wolff (1998), p. 101). By any standard, the economic damage and human suffering of smallpox thus exceeded the current epidemic's maximum seroprevalence of 22.10% (Iran) and 15.02% (Sweden) and estimated case fatality of roughly 1% (the highest estimates are 1.29% (Italy) and 1.15% in Spain).[7]

The disastrous smallpox situation changed dramatically with the discovery of the cowpox vaccination by Edward Jenner in 1798. Cowpox is a flu-like disease with local skin eruptions which conveys immunity against natural smallpox without threatening the life of the infected (Jenner (1798)). Given its enormous economic and strategic potential, governments all over Europe promoted vaccination, some of them like the German states of Baden (1815) and Wurttemberg (1818) making it even mandatory by law. The experience of Baden's and Wurttemberg's smallpox prevention was a „trial and error"-process which probably foreshadows the future of Covid19. After an initial stage where no safe vaccine was available, the majority of the population welcomed vaccination. The introduction of cowpox vaccination and early efforts at its popularization mark the second stage. Popular acceptance notwithstanding, coverage in this period remained incomplete and a smallpox epidemic in 1815/16 set the trigger for the introduction of compulsory vaccination. In this third period - the age of mass immunization - popular support vanned and the authorities faced new challenges and opposition from diverse social groups. The reason was that by mid-century, it became apparent that a single dose of the vaccine did not ensure life-long immunity. Moreover, declining prevalence rendered smallpox a less palpable threat and the inconveniences of vaccination started to play a role in individual decision-making. Precisely at this point, the success of the vaccination system in Baden and Wurttemberg started to differ: Whereas Baden maintained high compliance and almost universal coverage, anti-vaccionism gained momentum in Wurttemberg and led to a substantial reduction in the vaccination rate. Finally, the divergence of the two systems stopped after the foundation of the German Reich in 1871. The reason was exogenous: The smallpox pandemic which raged after the Franco-Prussian War led to the introduction of a standardized vaccination law and standardized procedures at a national level in 1874.

In sum, decision makers in the 19th century were confronted with the same swaying support for preventive policies and had to address the same logistic problems in the massive proliferation of vaccines as today's epidemiologists. These challenges reflect fundamental

[7] Data on seroprevalence are from Rostami et al(2020); Case fatality has been summarized in a meta-analysis by Meyerowitz-Katz and Merane (2020)

patterns of rational economic incentives. Hence they can be predicted and analyzed based on a combination of mathematical epidemiology and social welfare theory. Let us discuss these tools briefly in the next section.

4. The Theory of Epidemics: Why does implementation matter and why does it matter more in the course of time?

To understand why even the best - i.e. welfare maximizing - policy may face popular resistance some basic knowledge of mathematical epidemiology is needed. Epidemiologists conventionally depict the dynamics of communicable diseases based on 'compartmental models' which study the evolution different epidemic states (or 'compartments') over the course of the epidemic. A tractable and parsimonious model of this family is the so-called SIR model (Kermack and McKendrick, 1927). SIR stands for three epidemic states, "susceptible" (all healthy but potentially infectible individuals), the "infected" and the "removed" (those who have survived and acquired immunity or have died from the disease). The flows of people between the epidemic states are modelled by a set of differential equations:

$$\dot{S} = -\beta SI \quad \text{(i)}$$

$$\dot{I} = \beta SI - (\gamma + \delta)I \quad \text{(ii)}$$

$$\dot{R} = (\gamma + \delta)I \quad \text{(iii)}$$

The above equations are easily interpreted. First, the number of exposed individuals declines if a person contracts smallpox (or Covid19). Hence, if I members of the population are infected at time t and pass the disease with transmission probability β to one of the S hitherto uninfected persons, the infected compartment will grow by exactly βSI new cases. Conversely, if a patient recovers (with probability γ) or succumbs to the disease (with probability δ), he or she moves from the infected to the removed class. Hence, if the infective spell has an average duration of $1/(\gamma + \delta)$, there will be $(\gamma + \delta)I$ transitions from I to R as described by (ii). The model is completed by the dynamics of the removed class in equation (iii) which shows how the removed compartment grows at each time step due to transitions from the infected class.

The basic SIR model simplifies the complexity of real epidemics drastically but it allows us to study the incentives of rational planners and private individuals: Central decision makers like governments or epidemic task forces measure the performance of alternative prevention strategies based on the total number of avoided infections. Conversely, private individuals are concerned with the individual risk of contracting the disease from infected contacts. To see at which inflection points of an epidemic public and private preferences for prevention differ,

we derive three indicators from the SIR model. The first indicator reflects if an epidemic is under control: The so-called "basic reproduction number" R0, is defined as the number of secondary infections caused by a newly infected person. Rearranging the equations of the SIR model, R0 is formally defined as:

$$R0 = \frac{\beta S}{\gamma+\delta} \cdot \frac{1}{N} \approx \frac{\beta}{\gamma+\delta},$$

where N is the total population.[8] The key information contained in this expression is that a disease can only spread and turn into an epidemic, when the first infected "patient zero" produces more than one secondary infection (R0>1). Otherwise, the pathogen will disappear from the population when all initial victims have recovered or died. For epidemic diseases like smallpox and Covid19 this is obviously not the case. The question is therefore what the SIR model predicts if the indicator R0 exceeds the critical level of 1. If R0>1, the problem of the health authorities consists in equating the marginal costs of prevention with the corresponding marginal benefit (as measured by avoided infections). To keep the exposition simple, we model prevention policies (vaccination or social distancing) as a direct reduction of the susceptible compartment. In other words, increasing the level of prevention by a marginal unit reduces the pool of potential disease victims by exactly one marginal unit at the beginning of the outbreak.[9] Next, integrating (ii) over time gives the number of all persons who will become ill at some point of the epidemic. Skipping the details of this calculation - interested readers will find it in Boulier et al. (2007) - it can be shown that the avoided number of infections and hence the marginal social benefit (MSB) of prevention is given by:

$$MSB = \frac{S_0 - S_\infty}{S_0} \cdot \frac{1}{(1-\frac{1}{N}R0S_\infty)} \text{ (iv)}$$

MSB corresponds to the welfare gain, society makes by removing an additional unprotected individual (via vaccination or isolation) from the initially susceptible population. The first term on the right thereby reflects the risk of infection of the representative susceptible.[10] The second term captures the expected number of secondary infections which occur if the last marginal susceptible remains unprotected. Intuitively, it can therefore be interpreted as a measure for the benefit from herd immunity.[11] A central feature of *MSB* is that it is not linear in the level of prevention although its concrete curvature depends on the epidemiological

[8] Since $S \approx N$ at the beginning of the outbreak or for sufficiently large populations, R0 simplifies to $R0 = \frac{\beta}{\gamma+\delta}$.

[9] This would be the case for a vaccine which was 100% effective.

[10] The term divides the number of persons who become infected between the outbreak (time zero) and the end of the epidemic (time ∞) by the number of initially unprotected individuals.

[11] If the marginal individual contracts the disease, there will be S/N×R0 new infections. In the limit (with all second-, third-, fourth-, etc order infections accounted for, this leads to the $\frac{1}{(1-\frac{1}{N}R0S_\infty)}$ cases which feature in (iv) .

parameters R0, β, γ and δ. In particular, the effect of prevention declines by little (or even increases) as the first members are removed from the susceptible pool, then flattens and decreases rapidly the closer the herd immunity threshold. Once herd immunity is reached, prevention has no effect and *MSB* drops to zero.

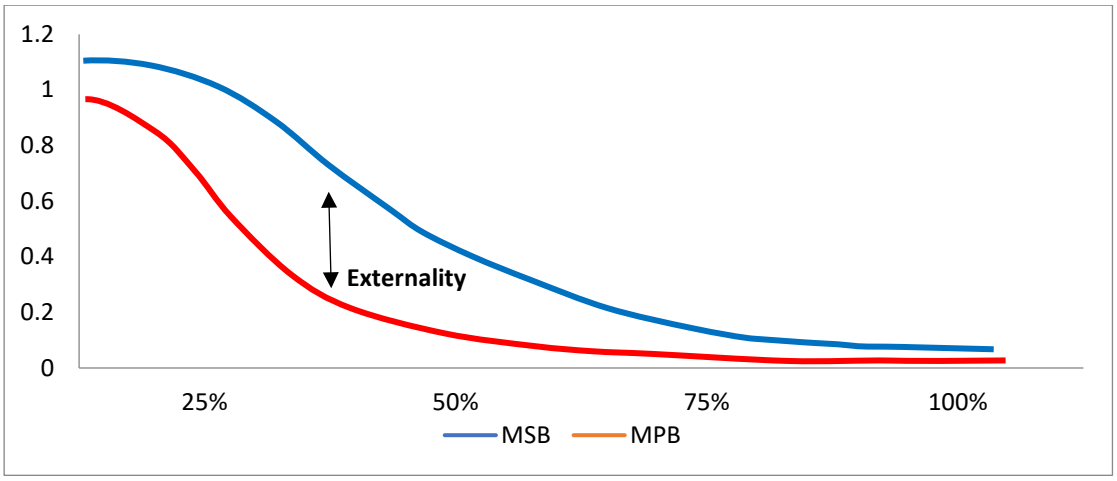
Contrary to the problem of the central planner, the effect of herd protection is not present in the optimization problem of private individuals. Accordingly, the marginal private benefit (*MPB*) of prevention is only proportional to the risk of contracting the disease but not to the number of avoided secondary infections. Hence, it can be written as below:

$$MPB = \frac{S_0 - S_\infty}{S_0} \cdot K \quad \text{(v)}$$

where *K* is a constant which reflects the individual valuation of remaining uninfected.

Since our purpose is to understand the incentives of the health authorities to impose and of the citizens to comply with anti-epidemic measures, the relationships (iv) and (v) provide two important insights. First, for any type of epidemic disease (i.e. $R0 > 1$ and $S_0 \neq S_\infty$), the social benefit of marginally increasing prevention is strictly greater than the private one. And second, although the rates at which *MSB* and *MPB* decline as prevention is reinforced depend on epidemiological characteristics, *MSB* falls later and less rapidly than MPB because herd prevention needs a critical mass of protected individuals before it becomes effective. However, once the critical mass is reached, the indirect effect of herd protection balances the decline of individual risks and keeps the social benefit from prevention on higher levels than the private. As a result, the prevention externality varies systematically but *not* monotonously in the level of prevention: At first, it is small because infection risks are high and so are private incentives for protection. As more precaution is taken, prevalence falls and the gap between privately and socially preferred prevention levels widens. Finally, if measures like vaccination reduce the pool of potential disease victims to the point where the pathogen cannot spread anymore, MSB and MPB both decline to zero and the prevention externality disappears. The relation between the level of prevention and externality is shown in figure 1:

Figure 1: Marginal Social and Private Benefits of Prevention Policies



The SIR model and the figure suggest clear implications: One is that imposing strict anti-epidemic policies is at first easier because private benefits are high and close to *MSB*. However, once this political „honeymoon effect“ vanishes, falling prevalence reduces the expected risk of contracting the disease and the perceived costs of prevention weight stronger in the individual decision problem. Hence successful prevention may suffer from a „winner's curse“ unless the state manages to communicate the continued importance of anti-epidemic measures and unless it succeeds in maintaining effort costs at popularly accepted levels. Whether this "winner's curse" jeopardized the success of smallpox prevention in Baden and Wurttemberg, how administrations addressed the problem and what can be learnt for a vaccine strategy against the new SARS-Cov-2 will be the next step in our discussion.

5. Historical Case Study –Baden and Wurttemberg:

5.1. *The First Stage: Communicating the Benefits of Vaccination*

Baden and Wurttemberg followed the predictions of the theoretical model in the sense that private demand for vaccination was high as long as the disease was endemic, In Baden for instance, vaccination had been introduced in 1803 and as soon as 1804, *officially confirmed* inoculations amounted to respectable 14.773 with public health officials estimating the total number around 25.000.(Maler (1804), p.62) Similar success was recorded in Wurttemberg,

where numerous doctors offered free vaccinations, some of them spending enormous time and effort to expand the measure to remote villages.[12]

However, the two states also obeyed to the model in a second sense: Although smallpox was still a palpable threat, individual demand for the new technique remained below the politically desired level. This is theoretically unsurprising since the model predicts that the prevention externality keeps vaccination below the heard immunity threshold. Still, empirically, matters are less clear: How could it be that a disease which caused death or disfigurement did not inspire fear and boosted the demand for immunization? Why did not everybody receive the lifesaving vaccine and why did many not seek it? Let us tackle this unsettling question and discuss potential implications for future vaccination strategies against the coronavirus.

5.1.1 A Usual Suspect but Not the Culprit – Monetary Costs of Vaccination

A Straight-forward explanation for stalling demand are high costs of vaccination. However, this intuitive notion is misleading because the governments of Baden and Wurttemberg regulated and subsidized vaccination fees: Prior to the mandatory vaccination act of 1818, getting a child inoculated would cost a Wurttemberg family 15 Kreutzers. After 1818 this price was reduced to 12 kr. In 1815 prices, this implies that the fee of a vaccination amounted to no more than the price of 5 pounds rye bread or 1.5 pounds pork (Wolff(1998), p. 165). For Baden, one finds that a vaccination would cost between 27 and 18 Kreutzers which translates into 10 (7) pounds of bread or 1.2 (0.8) pounds of pork in 1806 Mannheim prices (Krauß, (1993), p. 89). Laws and ordinances in both states further stipulated, that vaccinations had to be offered free of charge to all families who received poor relief or were classified "indigent" by their municipality. Depending on the district, this classification applied to 10-30% of the Badenese population for which data exists. This fraction was even higher in rural districts because the inhabitants of remote farms were routinely treated as "poor" which increased the share of publicly financed vaccinations to more than 50 percent.[13] Those who did not fall into this category - the urban and rural middle class - had an annual income of 600 fl (=Gulden) or more (Selgert (2018), p.72). Assuming 250 working days, this corresponds to 2.4fl or 144 Kreutzers a day. Hence, for those who had to pay the vaccination themselves it was a minor cost and for those who could not afford foregoing 10 pounds of bread it was costless anyway.

[12] Documents from various sources: Schwäbische Chronik, 16. 10. 1801, p. 365; M. Lächlin, Geschichte der allgemeinen Einführung der Kühpockenimpfung in Botnang in den Jahren 1801, 1802 und 1803, unpublished manuscript 1804, reprint in: G.Cless, Impfung und Pocken in Württemberg, Stuttgart 1871, p. 105-108

[13] GLA Karlsruhe 236-16026(Sanitary Commission), Classification: "Medical Treatment for Indigent Persons"

5.1.2 Mistrust in modern medicine:

Misinformation, ultra-conservative religious beliefs and traditional conceptions of smallpox etiology put more important obstacles into the way of vaccination than monetary costs. Folk wisdom held that smallpox was an inevitable ailment and necessary to eliminate evil substances from the body. Sometimes, the idea of physical purification coupled with the belief that epidemics were a divine punishment. Put to the extreme, the argument lead to the rejection of preventive methods as acts of evading divine justice and trespassing into heavenly prerogatives (Baldwin (1999), p. 275). Like other European countries, Baden and Wurttemberg were not immune against these beliefs as the following passage from the medical topography of the town of Gemünd illustrates:

> "...Thus, the following prejudice is deeply rooted [in popular opinion], that the natural smallpox poison is a priori contained in the body (...), that this poison cannot be emitted from the body through the few pustules [after vaccination] and that this will eventually give rise to other diseases even if it might prevent the outbreak of smallpox."(Werfer (1813), p. 146)

In spite of the vaccination's early success, these attitudes did not vanish in the course of time. If anything, they took an elitist and pseudo-scientific inflection from midcentury onwards. We will discuss this tilt later. For the time being, the central finding is that misinformation and unfounded medical beliefs mainly affected religious, traditional, low skilled and/or rural strata of the population. Interestingly, current studies observe virtually the same and conclude that vaccine refusal is strongest in groups at the margin of society (Aharon et al., 2016).

In terms of the theoretical model, belief-based resistance can be interpreted as part of the initial gap between private and socially optimal vaccination. The reason is that fundamentalist and uninformed currents exist even if the risk of infection suffices to convince any „rational"individual of vaccination. Since this opposition is a minority view under high prevalence, public health regulations can successfully be enforced through a mix of legal coercion, peer group pressure, rewards and health education. Yet while this window of opportunity is open when the group of potential offenders is small, easily identified and not backed by community support, it closes rapidly if the state is incapable of addressing „rational" fears concerning "shoeleather-" and „pain costs".

5.1.3 Rational responses to economic disincentives:

„Shoeleathercosts" played a major role for parents in rural areas. The main reason was the initially deficient organization of the vaccination system. For example, parents who carried their infants to the closest vaccination facility used to spend hours on more or less accessible field tracks in the early. Adding to that, the cowpox vaccination involved sizeable pain costs:

Typical were two to three weeks of painful local skin eruptions and flu-like symptoms like fever, nausea and headache, possibly coupled with acute conjunctivitis. At least one adult would therefore have to refrain from income-earning activities in order to take care of the vaccinated children. A Baden peasant summarized the high opportunity costs stating that "he could not afford having his children made sick in the middle of the harvesting season."[14]

The normal pain costs were moreover inflated by the fear of harmful side effects – especially the transmission of syphilis. Relatively rare events they were, such incidences never failed to attract media coverage and resembled the cases of "vaccine hysteria" we know from recent history. Thus, parents in the 19th century feared having their children infected with syphilis just as vaccine critics today who associate measles vaccination with autism - a debate which was triggered by a single, scientifically unsubstantiated study (Eggertson et al., 2010, p.182).

Summing up, the early stages of smallpox vaccination in Baden and Wurttemberg confirm what economic theory predicts: The two states reached the point where the prevention externality began to grow in the first decade of the 19th century. Vaccination had kicked off and prevalence declined. However, a sustained growth of immunization rates – up to the level where the disease would have been eradicated – was not attained in neither of the two states. Instead, a gap between individually and socially optimal prevention became apparent and called for central intervention. As this intervention is concerned, our analysis provides three important insights: First, even if a Covid19 vaccine became marketable soon, subsidizing or offering it for free would not guarantee universal immunization uptake. Second, the reasons for this are non-monetary and policymakers must address the challenge of creating an infrastructure which provides convenient access to safe vaccination. Third, due to the historically and presently wide-spread mistrust against scholarly medicine, information plays a key role in the success of the vaccination program.

The puzzle health authorities had and still have to solve therefore consists in designing a set of not necessarily monetary incentives which guarantee that people really prefer a relatively safe and effective vaccine over hazardous traditional cures or the misuse of disinfectants and house cleaning products today (Le Roux (2020), p.1). To see which options policymakers have and which policies did or did not promote immunization, we now move our focus to the institutional and organizational arrangements implemented by Baden and Wurttemberg in the

[14] Instruction of the Sanitary Commission, August 2nd,1815 (Baden), Vaccination Instruction, June 25th 1818 (Wurttemberg)

first half of the 19th century. As it will turn out, the strategies of the two states were initially tailored to the need of overcoming the vaccine hesitancy of low skilled, traditional and religious groups. As such, they yielded mixed success, but as predicted by the theoretical model, they modification once the prevention externality started to grow and anti-vaccination ideology entered the bourgeois middle class.

5.2. Policy Responses I: Facilitating early systematic prevention

The initial response was paternalistic if not authoritarian: Both states made vaccination mandatory at roughly the same time (i.e. in 1815 and 1818) and subsequently punished breach of the vaccination laws with fines from 0.5 to 32 Gulden (=fl) in Wurttemberg and 1 to 8 fl in Baden. [15] An artisan or a low ranking civil servant would therefore pay up to 5% (Wurttemberg) and 1.25% (Baden) of his annual income for breaking the law. [16] Legal coercion was thereby blended with attempts to gain popular support by positive incentives. Examples include "vaccination medals" for patients and the introduction of fill-in forms which local officials and policemen could use to notify the central Sanitary Comission of outbreaks in Baden. The next important feature was the reduction of patients' shoeleathercosts. Both governments provided for public vaccination campaigns which were hold every year such that parents in rural areas could have their offspring vaccinated before or after the sowing and harvesting season. In Baden, this system became the leading pattern and was standardized up to the point that almost all children attended to public vaccination campaigns that took place every year in May and June and again in October and November.[17] In Wurttemberg public and private vaccination existed side by side which - as will be shown later turned into an important weakness when the prevention externality became notable.

Besides efforts to improve access, both governments also engaged in creating direct incentives for immunization. One part of these activities would today be labelled as "influencing": Observing that vaccinators faced far less obstacles when members of the local elite supported the new measure.[18] Both states took steps to enlist the support of the circles

[15] Laws and ordinances in: (Baden) Philipp Carl Baur von Eiseneck, Sammlung sämtlicher Gesetze, Verordnungen, Instructionen, Belehrungen und Entscheidungen, welche in dem Gross-Herzogthume Baden über Gegenstände der Gesundheitspolizey erscheinen sind, Karlsruhe 1830, (Wurttemberg): Albert Renscher (ed.), Vollständige, historisch und kritisch bearbeitete Sammlung der württembergischen Gesetze, Stuttgart 1830;

[16] As in the case of the price of a vaccination, the calculation assumes the annual income s taken from Selgert (2018).

[17] The corresponding laws and ordinances can be found in: (Baden) Philipp Carl Baur von Eiseneck, Sammlung sämtlicher Gesetze, Verordnungen, Instructionen, Belehrungen und Entscheidungen, welche in dem GrossHerzogthume Baden über Gegenstände der Gesundheitspolizey erscheinen sind, Karlsruhe 1830, (Wurttemberg): Albert Renscher (ed.), Vollständige, historisch und kritisch bearbeitete Sammlung der württembergischen Gesetze, Stuttgart 1830;

[18] A report to the Badenese Sanitary commission noted in 1813 that vaccination was generally welcomed and more or less universally established in all localities where local officials, teachers and the clergy joined forces to make the merits of prevention known in their

they considered influential. Especially Wurttemberg provides striking statistical evidence for the relative importance of elite support: In the Jagst-District (Jagstkreis) a group of schoolteachers and clergymen set out to promote the universal revaccination of all young adults. Having no other means to accomplish this aim, they came up with the ingenious albeit morally questionable idea to officially announce a forged "amendment" to the vaccination act which required the revaccination of all 14-year olds. Local officials saw no reason to prevent the staging with the result that the district's vaccination rate was about one third higher than in other parts of the country. Accordingly, smallpox mortality remained at negligible levels and hardly reached *half* the size of the Wurttemberg average (Cless (1875), p. 72).

Finally, at least Baden also took systematic steps to clearly communicate the benefits of vaccination and to inform about potential risks. Thus the interested public could easily access the results of the annual vaccination campaigns as they were published both in the state's bulletin and in local periodicals.[19] This clear and regular communication was probably an important antidote against the rising vaccine resistance of the second half of the 19th century. Thus, governments are well advised continuing the strategy of disseminating health relevant information through regular press conferences and expert briefings in the mass media. Projects like the EU campaign against misleading information about the coronavirus[20] or corresponding good practice policies by social media platforms must therefore be considered not just useful *additions* but *key* elements of successful anti Covid19 prevention. For, the speed at which smallpox vaccination took off was not a simple matter of fining disobedience. Rather it rested on trust gained through accessible information, disseminated in a multichannel way, including official bulletins, newspapers, talks and personal interaction with teachers, local officials and the clergy. Moreover, getting vaccinated had to be as „comfortable" and costless as possible which meant not just limiting fees but also timing and closely supervising the standards of the service. The example of Baden shows that standardized mass campaigns are a promising strategy to reach this aim because they create regular habits – and thereby reduce the fear of immunization – and because the associated scale effects help to reduce the effort costs for patients and vaccinators alike.

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communities or to allay fears of harmful consequences and to organize public vaccination campaigns. On the other hand, the report also remarks that universal immunization was virtually impossible, if local officials refused to set a good example by consenting into the vaccination of their offspring. [57] Cless (1875), pp.3-13

[19] Besides the number of successful vaccinations, information on smallpox infections and deaths, these publications also reported the number of failed vaccinations, irregularities and accidents in case they occurred.

[20]The campaign is described in the following webpage: https://euvsdisinfo.eu/category/blog/coronavirus

5.3. New challenges in the era of mass-immunization

5.3.1. Vaccine Resistance Revisited:

Mistrust in modern medicine continued to depress vaccination rates in the second half of the 19th century. Yet, as time passed, vaccine resistance turned from a rural to an urban and from a lower to an upper class problem. This process was chiefly initiated by the fact that prevalence had declined and that the temporal limits of the vaccination-induced immunity became apparent from the late 1820s onwards. The academic dispute about revaccination and the limitations of immunization made it to the popular mass media because it coincided with the political call for civic liberties and with the rise of „alternative medicine“. This problem was especially evident in Wurttemberg, where beginning with the revolutionary years of the late 1840s the liberal-democratic movement made mandatory vaccination a token of despotic ancien régime politics. Although this resistance was not fueled by epidemiological considerations, it channeled political dissatisfaction towards medical topics when the bourgeois anti-vaccination movement gained moment as it found an apparently charismatic and energetic leader in the person of the Stuttgart doctor Carl Georg Nittinger. By 1874 Nittinger had produced 25 voluminous tracts against vaccination and the Wurttemberg movement became one of the epicenters of German antivaccionism.

The heyday of vaccine resistance in the mid-19th century is unsurprising: Prevalence was at its lowest point such that - as predicted by the SIR model - secondary health risks and personal freedom began to matter. What remains a puzzle – and offers important insights for today - is that anti-vaccination movements succeeded in Wurttemberg whereas they played little role in Baden. As the following section will show, this divergence was strongly driven by the position doctors and health practitioners assumed in the two states. Hence, our focus will be on the incentives, the two vaccination systems created when the prevention externality was growing up to the point where it attained its peak.

5.3.2. Adverse incentives for Doctors

Doctors, nurses and pharmacists contribute more than just medical expertise to the fight against infectious diseases. As frontline health workers they are key actors in the implementation of prevention policies at the grassroots level. During the first wave of the coronavirus pandemic many health professionals have exhausted their physical and emotional resources in this task. As the virus persists – however – the limits of this commitment become

apparent: Today organizational deficiencies, income loss, unacceptable working conditions, the lack of protective equipment or even social exclusion, discrimination and violence are publicly denounced.[21] These problems are not new: Doctors in Baden and Wurttemberg voiced similar grievances when the two states entered the era of mass immunization. Like patients who became more susceptible to anti-vaccination ideology when the gap between private and social welfare widened, the medical profession lost its enthusiasm for vaccination when the operation turned from a medical breakthrough into a daily routine.

Physicians' support for vaccination was limited by two factors: one was the fear that active involvement in prophylaxis would cost them their patients' trust. In extreme cases, rumors or misinformation could even produce violent assaults as the following case illustrates: In the 1830s, a vaccinator in rural Wurttemberg collected vaccination lymph from the child of a mother who suffered from epilepsy. Fearing that the mother's disorder could be transmitted through the vaccine, the villagers chased the surgeon from their village. One year later, when the health officer from the capital came to investigate the issue and to perform the missing vaccinations, he was welcomed with "stones and pitchforks".[22]

Fortunately, events like the above remained exceptions. If at all they happened in remote areas and briefly after vaccination had become mandatory. Since the prevention externality was small at this time, the majority view was favorable and physicians who confronted vaccine resistance incurred little risk: Their opponents were mainly peasants or the city poor – no particularly solvent clientele whose concerns were easily dismissed as superstition and shortsidedness. Yet, this changed when vaccine skepticism became fashionable among educated well-to-do households. From mid-century onwards, middle and upper class anti-vaccination activists exerted systematic pressure on vaccinating doctors. Unlike the early opposition against immunization, physicians apparently viewed these activities as serious threats for their income and reputation. For example, the vaccination reports of the German Empire show that private doctors signed up to 15 times as many certificates to exempt children from mandatory vaccination than their publicly salaried peers.[23] Since they vaccinated identical birth cohorts and operated in the same districts many of these certificates might have been simple courtesy. Contemporaries were aware of this fact and the anti-vaccination movement provided its followers with articles and books that recommend relying

[21] See: Basu et al. (2020) for income losses, Theorell (2020), Zhang et al. (2020), Di Tella et al. (2020) for working conditions
[22] StAL E162-I-2133, Internal Report on Vaccination to the Ministry of Inner Affairs, Stuttgart 1831
[23] The information is contained in the annual vaccination reports *„Verlauf des Impfgeschäfts*" in „*Arbeiten aus dem Kaiserlichen Gesundheitsamte"* (Studies of the imperial health office) issues 1886-1897

on private doctors because they were „certainly more inclined to respect the preferences of their clients" (Securius (1894) p.10). Finally especially doctors who sympathized with naturopathic medicine joined the opposition against mandatory vaccination either as a matter of conviction or because it gave them an advantage in the competition for wealthy, liberal - and often vaccine skeptical – bourgeois patients.

Even if physicians did not need to struggle with opposition from patients, infrastructural deficiencies lead to unacceptable working conditions which jeopardized the success mass immunization. In particular country doctors faced important traveling costs and bureaucratic wrangling to obtain payment. Their ordeal is nicely illustrated by a Baden country doctor:

> "Running a medical practice in the countryside is by far a greater challenge than practicing in the city. .[...] There was hardly a night which passed without the door-bell ringing and calling me to visit a patient. By no way, I could have eaten my meals at regular hours and finally I resolved to wearing far too light clothes [for the cold season] because they would not impede my movement on the long horse rides. In the end, even my horse could no longer bear the daily drudgery and I needed a second one" [24]

That these obstacles cooled doctors' zeal for vaccination is understandable but it was dangerous: Cowpox vaccinations failed relatively often to provoke a sufficient immune response. Vaccinators therefore needed to revisit the vaccinees 5-7 days after inoculation.[25] If this duty was not fulfilled with diligence, a substantial number of failed vaccinations passed unnoticed which gave the health authorities a biased impression of immunization levels and made targeted reactions to disease outbreaks difficult to implement.[26]

The above examples illustrate that the support of the health sector is central for the popularization of prevention strategies as well as for the efficient assessment of the prevailing epidemiological conditions. Hence, besides addressing the vaccine hesitancy of laymen, designing payment and incentive schemes for health professionals is the second critical task of mass immunization policies. For, once the initial enthusiasm fades, symbolic gestures like the daily applause are no strong motivation anymore.

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[24] Adolf Kussmaul, Jugenderinnerungen eines alten Arztes, Reprint München 1960, p. 295[24] GLA Karlsruhe 236-16026 (Sanitary Commission), Report of the *Physicus* of Pfullendorf, April 13th

[25] The need to supervise the success of the vaccination remained a problem of smallpox immunization programs until the WHO global eradication campaign of the 1970s; See numerous corresponding laws and ordinances in: (Baden) Philipp Carl Baur von Eiseneck, Sammlung sämtlicher Gesetze, Verordnungen, Instructionen, Belehrungen und Entscheidungen, welche in dem GrossHerzogthume Baden über Gegenstände der Gesundheitspolizey erscheinen sind, Karlsruhe 1830, (Wurttemberg): Albert Renscher (ed.), Vollständige, historisch und kritisch bearbeitete Sammlung der württembergischen Gesetze, Stuttgart 1830

[26] Especially in Wurttemberg, the impression of a rather perfunctory attitude towards documentation is further supported by various pieces of anecdotal evidence: In one case, a physician indicated that the vaccination reports of his predecessor were utterly unreliable because they indicated not a single unsuccessful vaccination - instead of the usual 10-20% failure rate. The lists also contained passages in which dozens of vaccinations and follow-up visits had apparently been filled in just a few days before their official submission to the health department. In another case, a doctor who was reprimanded for shirking his documentation duties because he not only refused to revisit vaccinees in rural areas but also delegated this responsibility to his untrained 18 year old son whom he moreover entitled to collect a private fee of 1 gulden per visit. See: StAL E162-I-2133, Report of the Amtsarzt of the Schwarzwald district to the Medical Commission, November 13th 1827, StAL F184-III-BÜ60, Letter to the Oberamtsarzt of Mergentheim, October 19th 1891

5.3.3. Proliferation of Vaccines

The third and final major challenge of universal immunization consisted in difficulties to obtain high-quality vaccine. These problems stemmed from the fact that techniques to preserve and cool the vaccine remained on rudimentary standards throughout most of the 19th century. The lymph used in the process was either derived from the dried material of some previous vaccination or was directly transferred from the pustules of one vaccine to another. In the first case, chances were high that the lymph had degenerated during storage. In the second case, doctors had to make sure that there was an unbroken "supply" of individuals seeking vaccination in order to maintain the process of vaccine transmission. If this requirement was not met, the risk was high that interruptions in the supply of lymph prevented a rapid response in case of unexpected epidemic outbreaks of smallpox.[27]

As potential vaccines against Covid19 are on clinical trial, it is foreseeable that today's health planners will be plagued by similar difficulties of production and distribution as their ancestors in the 19th century. For, although technology has advanced so have the needs of modern vaccines: The most promising Covid19 vaccines need storage at -50 to -70 centigrades, a requirement which cannot be met by the traditional distribution networks of pharmacies, clinics and primary care units. Identifying the characteristics of historical institutions which solved the problem of supplying and restocking vaccines in a framework of mass immunization will be one of the central topics in the next section.

5.5. Policy Responses II: Adressing the challenges of mass immunization

5.5.1. Reducing costs and creating trust through habitual campaigns

The first important difference in the implementation of the vaccination laws was that Baden adopted a system of bi-annual vaccination campaigns in all bigger municipalities. This was a compromise to keep the „shoeleathercosts" of patients and vaccinators at feasible levels. On the one hand, physicians no longer had to visit every single hamlet to perform vaccinations and follow-up inspections but could conveniently fulfill their duties by touring the larger communities of their district. On the other hand, although there were travel expenses for the

[27] This particularity is discussed both by Cless (1875), ch1 and Franz Heim, Historisch-kritische Darstellung der Pockenseuchen, des gesamten Impf- und Revaccinationswesens im Königreiche Württemberg, Stuttgart 1838.

inhabitants of very remote farms or villages, these costs were capped by the fact that the regular vaccination dates allowed to plan in advance and to choose the closest locality. Besides „shoeleathercosts", the regularity of the procedure also affected popular trust in the policy. In many villages, the vaccination campaign turned from an intimidating or at best annoying operation into an opportunity to meet and chat with family and friends. This went as far as to prompting complaints by the vaccinating doctors: In the late 19th century, one of them literally begged the authorities to stop facilitating inns or restaurants for the annual vaccination campaign. The mothers of the vaccinees, the desperate doctor wrote, "enjoyed the gathering", socialized and "had drinks" such that the pub was rapidly overcrowded and finishing his task in due time was impossible.[28] Habit formation of this type certainly contributed to the fact that Baden's citizens were accustomed to mass vaccination and – in contrast to their Wurttemberg neighbors who lacked this regular and comprehensive service – hardly opposed it. Finally, by prioritizing public mass vaccination, Baden's health authorities chose a strategy which performs particularly well in securing popular compliance according to ongoing research in social psychology: They made sure that there was no need for vaccinees to take specific effort or act as first movers. Rather, by complying with the law, they joined a group of neighbors, family and friends who all followed the same custom and social consensus. Thus, getting one's children vaccinated was „what is normal and what good citizens should do". Conversely, refusing the operation required taking a stance and – by not showing up on a vaccination day – publicly opposing the general consensus. The long-term success of Baden's public vaccination regime therefore supports what authors like Steefland et al (1999), Bish et al (2011) and Blume (2017) have found in different micro-settings: Well organized mass vaccination creates a positive re-enforcement of group dynamics which - in turn - help to alleviate fears and put pressure on individuals to get vaccinated even when prevalence is low and the prevention externality high.

5.5.2. Sticks and carrots: Tenuring public vaccinators and providing incentives

The smooth functioning of the mass vaccination system depended crucially on the Badenese authorities' disposal of graduated doctors who performed this service. University graduates in medicine were not lacking in Baden because the country's two universities (Heidelberg and

[28] The episode is described in the vaccination report in the 8th issue of *Medizinalstatistische Mitteilungen aus dem kaiserlichen Gesundheitsamte,* p. 102. Interestingly the same was **not** recorded in Wurttemberg. Much to the contrary: A few yesrs later, a Wurttemberg vaccinator suggested there should be no seperate waiting rooms in the vaccination facilities. He noted that the mothers would spend all the time discussing conspiracy theories and hoaxes about the dangers of vaccination. As a result, many complained and some refused downright having their children vaccinated. See: Information on the statistics of smallpox in *Arbeiten aus dem kaiserlichen Gesundheitsamte"* vol.5, 1889, p. 82

Freiburg) were among the biggest and most prestigious medical faculties in the German speaking countries. The high "supply" of young doctors allowed the country to coordinate and closely control the vaccinators' performance. Specifically, the right to vaccinate was restricted to the district "*Physicus*", that is, to an academically trained doctor who was hired and paid by the government. Things were profoundly different in Wurttemberg where the right to perform vaccination was given to any licensed medical practitioner, including country surgeons. This initially costless and flexible solution eventually turned into a weakness because the professional capacities of Wurttemberg's many country surgeons varied so strongly that the quality of their services was unpredictable for patients and the health bureaucracy. The lower urban classes and the inhabitants of remote villages therefore faced the choice between leaving their children unprotected or permitting their vaccination by one of the more or less trustworthy medical practitioners who served the clientele established doctors did not bother to take care of. As a consequence, Wurttemberg with its small number of publicly employed and supervised vaccinators saw numerous unpleasant incidents ranging from the use of badly stored and ineffective vaccine to complete lack of follow-up documentation and from the accidental transmission of other infections to the issuing of forged vaccination certificates.[29] Hence, in the sense that the Badenese authorities could direct funds and recompensations selectively to physicians who had rendered service to the cause of vaccination, Baden's reliance on few government-appointed doctors again proved superior to the fragmented solution of its neighbor. Moreover, as the vaccinating doctors in Baden were tenured officials, their further career – including the possibility to move from unpopular remote districts to the metropolitan areas of Mannheim, Heidelberg or Karlsruhe – depended on the degree by which they fulfilled the expectations of the health department. In other words: their incentives to meet the immunization targets and the documentation standards were higher than those of their Wurttemberg confreres. This became a central advantage from mid-century onwards. For, the revolutionary 1840s and 1850s coincided with a period of relatively low smallpox prevalence in which the prevention externality was maximal and the potential for widespread vaccine hesitancy high. In Wurttemberg, where vaccination was performed by private doctors who depended on their patients' willingness to pay, the medical profession did little to prevent that bourgeois and liberal circles turned against mandatory vaccination to express their opposition against autocratic political structures. By contrast, Baden largely avoided this unfortunate intermixture of epidemiological and socio-political issues because its vaccinators

[29] Examples were drawn from StAL, E 162-I-2137

were independent of popular discontent. Many Badenese physicians therefore helped to de-emotionalize the discussion about vaccination and some like the dean of the medical school at Freiburg University, Adolf Kussmaul, resolutely defended the cause of immunization in popular books and newspapers (Kluge (2002), pp. 50-57).

5.5.3. Guaranteeing Vaccine Supply through Coordinated and Centralized Provision:

The final major difference between the two German states related to the procurement of vaccine. Here too, the Baden authorities were more inclined to take matters in their own hands. In Wurttemberg, the collection of fresh vaccine was more or less confined to private channels and doctors heavily relied on their patients' willingness to provide lymph for subsequent arm-to-arm vaccinations. For the first third of the century, the sole exception to this rule consisted in a Wurttemberg law which exhorted the district doctors to collect and store fresh vaccine whenever there was an outbreak of natural cowpox and awarded a prime of 1 fl to any peasant who reported a case among his cattle.[30] In contrast to the piecemeal efforts of its neighbor, Baden was fast in backing up its immunization policies with an institutional infrastructure. In particular, the country was by far the first to establish public vaccination institutes (*Impfinstitute)*, that is, institutions where parents could have their infants vaccinated for free by specially appointed doctors. In exchange, they were obliged to allow the vaccinators to collect lymph from the children once the pustules had reached the proper stadium. Moreover, the vaccination institutes were assigned the respective tasks of vaccinating orphans and the city poor, of receiving and storing fresh strains of vaccine from medical institutions abroad, of collecting lymph from occasional eruptions of cowpox and of promptly supplying all doctors in their district with vaccine. All in all, Baden had four such institutes which were strategically located to serve the Northern parts of the country (*Impfinstitut* Mannheim), the capital and adjacent central regions (*Impfinstitut* Karlsruhe and *Impfinstitut* Freiburg) and the South (*Impfinstitut* Meersburg). They operated in relatively modest premises such that the Mannheim institute for instance consisted of no more than three rooms - a waiting and examination room and a small office for the doctor in charge. As a result, the costs of installing and maintaining the network of vaccination institutes remained moderate but guaranteed a surprisingly constant supply of vaccine. For, although complaints of vaccine shortage do appear in the early Baden sources, they vanish after 1810 and the otherwise highly detailed and carefully composed annual vaccination reports of the Sanitary

[30] Albert Renscher (ed.), Vollständige, historisch und kritisch bearbeitete Sammlung der württembergischen Gesetze, Stuttgart 1830

Commission do not allow the matter more space than the standardized statement that "the institutes successfully provided *all* district doctors with the due amounts of lymph."[31] How smoothly the system worked is strikingly apparent if one looks at actual outbreaks of the disease. The Baden infectious disease regulations stipulated that all children or – in case of severe outbreaks –the *entire* population had to be (re-)vaccinated on the spot. As a result, the detection of a smallpox case would inevitably lead to a sudden peak in vaccine demand. The vaccination institutes were however perfectly able to deal with such challenges as a number of successful revaccination campaigns illustrates: A particularly impressive example dates back to 1826/27 when the neighboring French region of Alsatia was hit by an epidemic that caused more than 12000 infections and claimed at least 2464 lives.[32] As Baden and Alsatia were economically far too integrated to suspend cross-country trade and mobility, the Badenese authorities implemented a comprehensive vaccination campaign in the entire border region. Due to this campaign the country managed to keep its 1826/27 smallpox mortality at the negligible level of 7 cases. In Wurttemberg on the other hand, lymph procurement not only remained a serious problem – with physicians' complaints of vaccine shortage numbering more than 30 for 1827 alone – but also prevented the fast containment of smallpox outbreaks. In fact, more than two decades after the 1826/27 revaccination campaign in Baden, Wurttemberg was threatened by an epidemic wave that entered the country from Switzerland in 1849/50. Yet, unlike its western neighbor 20 years before, Wurttemberg failed to contain the outbreak and recorded a peak morbidity and mortality with more than 7000 cases and 600 deaths in 1850.[33]

6. Assessment: Did Baden's or Wurttemberg's Smallpox policy yield superior welfare outcomes?

To draw the final lessons from Baden's and Wurttemberg's experience, we need measures to assess the success of the two states' institutional responses. A policy will rank highly on our success scale if it reaches high levels of popular compliance, if service delivery was possible

[31] For the period 1813-1861, these reports are available on an annual basis in: Ministry of Inner Affairs (ed.) Regierungsblatt für das Großherzogtum Baden, Karlsruhe various years.
[32] Victor Stoeber, Topographie et Histoire médicale de Strasbourg et du Département du Bas-Rhin, Paris 1864, pp.438-445
[33] Minutes of the Council oft he Kingdom of Wurttemberg (Verhandlungen der Württembergischen Kammer der Abgeordneten auf dem Landtag), 1862-65, vol.1 section 5, pp. 3363-70

at low costs and last - but most importantly - if the policy successfully reduced morbidity and mortality. Let us consider the three components one at a time starting with compliance.

6.1. Compliance:

Measuring compliance in historical populations is a challenge because commonly used tools like surveys and opinion polls are not available. To see if Baden's and Wurttemberg's citizens supported or at least did not resist vaccination, I combined information from different statistical and documentary sources. As mentioned before, contemporary observers characterized Wurttemberg as a hotspot of anti-vaccinationism while keeping Baden off the list of "resisting states". I checked if this verdict - which certainly reflects the presence of prominent activists – also prevails at the level of the general population: To this end, I first analyzed the coverage of vaccine critical opinions in popular print media. According to the catalogue of anti-vaccination literature published by the "London Society for the Abolition of Compulsory Vaccination" in 1882, a total of 16 books and pamphlets plus a monthly magazine were printed and issued in Wurttemberg compared to only 3 in Baden. Although the correlation between the strength of local vaccine hesitancy and regionally edited publications is not perfect (after all, anti-vaccinationists might have purchased literature from foreign editorials), it is nevertheless an indicator because leading vaccine critics tended to either self-edit their writings or relied on local editors.

To capture lower organizational levels of the anti-vaccination movement, I next studied evidence which becomes available after the *Reichsimpfgesetz* had made vaccination mandatory in the entire German Empire in 1874. The indicator in question is the number of petitions and - where available - the number of signatures calling for the abolition of the law. The minutes of the petition committee of the Reichstag record a total of 2900 petitions against the *Reichsimpfgesetz* which were filed between 1874 and 1896.[34] For the first wave of petitions (till 1875), the number of signatures rounded 30000 for the entire *Reich*. Only 161 signatures had been made by the citizens of Baden which corresponds to 0.55% of the complaints in spite of the fact that the Grandduchy contributed 3.5% inhabitants to the total population of the German Empire. (Ärztliches Vereinsblatt für Deutschand, vol.3, 1876, pp 97). Conversely, in Wurttemberg which had only 300.000 inhabitants more at the time, the anti-vaccination movement had gathered 5558 signatures and filed a summary complaint in

[34] 1896 is the last year for which data exists

1865 which was re-submitted to the Reichstag in 1875.[35] Hence, given that Wurttemberg opponents outnumbered Baden's by almost 20 times while its population was less than twice that of Baden, the qualitative evidence supports the intuition of 19th century observers.

The previous findings notwithstanding, publications and petitions fail to capture passive resistance, that is, parents who refused to have their children vaccinated. Unfortunately this form of incompliance cannot be measured directly because statistics of denunciations and fines survive only punctually and are not representative. Yet, it is possible to extract some information indirectly from the available sources: First, in the first years after the *Reichsimpfgesetz* had made vaccination mandatory for all children aged 1, an average of 4,0% of Wurttemberg parents were fined for breaking the law whereas only 0.34% in Baden.[36]

Next, for the period before 1874 - concretely for the 1850s and 60s - when the two states still had their own vaccination laws, there is annual information on vaccinations and births. In this time, the anti-vaccine movement had already gained momentum in Wurttemberg. As this information suggests, vaccination rates were indeed lower in Wurttemberg than in Baden and stood at 63% vs. 72% (Cless, 1875, pp. 71-80). The problem with this piece of evidence is that the data are not directly comparable. This is the case because the law in Wurttemberg stipulated that children had to be vaccinated in the first three years of life, while Baden imposed a cut-off age of only one year. Since infant mortality was high in both states, the earlier limit in Baden might have driven the fraction of vaccinated infants to newborns upwards. Fortunately, qualitative evidence and demographic statistics allow us to address this problem. First, documentary sources report that the vast majority of parents who observed the mandatory vaccination laws in Wurttemberg had their offspring vaccinated in the first year of life (Cless, 1875, p.14-23). Moreover, checking the mortality statistics of the 1850s to 1860s, one finds that of 1000 children born in Wurttemberg approximately one third died in the first year. In the critical age bracket >1 and <3, mortality was only 25 to 68 per thousand with an average of slightly below 50 per 1000. Hence of 1000 infants who had survived their first year, 950 would still be alive at the age of 3 when the vaccination law was binding. This implies that Wurttemberg's vaccination rate would have been roughly $63 \times \frac{1000}{950} \approx 66.3$ if immunization had been mandatory in the first year of life as in Baden. Hence, while a

[35] Correspondenzblatt des Württembergischen Ärztlichen Vereins, vol. 35, 1865 and minutes oft he seessions oft he *Reichstag* (Stenographische Berichte der Sitzungen des Reichsttags) 38. Sitzung, 26.01.1876

[36] Data are from Kaiserliches Gesundheitsamt (ed.), Arbeiten aus dem Reichsgesundheitsamte, vol. 1-5 (1884-89), the 5 year average is author's calculation

maximum difference of 3% in the vaccination rate might be caused by variation in the legally fixed immunization schedules, close to 6% remain unexplained. The gap between the two is more substantial than the two numbers suggest. For one, in terms of epidemiology, the estimated immunization rate which leads to herd immunity against smallpox is between 71% and 83%[37]. Thus, due to opposition, Wurttemberg would have missed the targed whereas Baden reached it or came at least close. Moreover, the difference is also substantial if put into the perspective of present-day behaviors: One of the most common standard vaccinations around the world is the measles-mumps-rubella vaccine (MMR). MMR vaccination among the 37 OECD member states varies between 100 and 70%. Yet, 30 of the 37 states attain quotas between 92 and 100% - i.e. they are closer than the *absolute* difference between Baden's and Wurttemberg's smallpox vaccination rates - and 19 of 37 are within 96-100, that is, closer than the *minimum* estimated difference between the two![38]

6.2. Cost efficiency:

Without denying the caveats concerning the data we have just seen, it still seems that Baden's central and highly standardized vaccination strategy enjoyed stronger support than Wurttemberg's. The next criterion based on which the two systems can be compared is their cost efficiency. Before doing this comparison it is important to note that including the entire range of vaccination related spending is neither possible nor desirable. The reason for this is twofold: First, vaccination does not appear separately in the two states' budget but is amalgamated into the positions "interior affairs" or "health commission". Archival resources exist, but only for single years and localities. Reconstructing the total costs of vaccination in both states at roughly the same point of time is therefore downright impossible. The second reason is that certain differences in the cost of health service delivery are not a proof of inefficiency but a result of attempts to ensure equal access to the system. In our specific case, this involves public subsidies for the vaccination of orphans or the poor. Since the fraction of poor households is unrelated with vaccination and since protecting all children irrespective of their parents' income, is a worthwhile aim *per se*, we do not want these subsidies to affect the assessment. What should - however - be considered are differences in the costs of installing and maintaining the prevention system, specifically, the costs of ensuring the sufficient and prompt supply of vaccine. As we have seen, Baden solved this problem by setting up

[37] Author's calculation based on the R0 reported in Gani, R., Leach, S. Transmission potential of smallpox in contemporary populations., in: Nature, vol. 414, 748–751 (2001).
[38] Data taken from the OECD database: https://data.oecd.org/healthcare/child-vaccination-rates.htm

vaccination institutes whereas Wurttemberg left the responsibility to obtain lymph to the doctors. The existing archival evidence allows us to juxtapose the costs of these two strategies and reveals surprising insights. Starting with Baden, the total spending on the vaccination institutes' network can be inferred from the surviving records which at - least for the Mannheim *Impfinstitut* - feature detailed cost calculations. These tables reveal that the costs of establishing the institute and paying a bonus to the two vaccinating public physicians amounted to 293fl 54kr. Assuming that this sum applied more or less to the three other institutes as well, the total costs of setting up the system would have come down to 1178fl 55kr. In the subsequent years, the Mannheim institute received a fixed budget of 192fl, whereas the smaller ones in Freiburg, Karlsruhe and Meersburg had to contend with 104fl, which gives a total of 504fl for the four institutes.[39]

How do these costs compare with other items of health spending in Baden and with the costs of the more decentralized system in Wurttemberg? The first part of the question can be answered based on the surviving Badenese national accounts. For 1808 these sources reveal direct central government spending of 18730fl on poor relief and medical treatment. Salaries for government-appointed health staff and costs for the maintenance of hospitals and asylums are not explicitly listed but figure in the section "public expenditure on police and health affairs". Yet, the corresponding numbers can be reconstructed using the budget bills of the Baden parliament. For selected years, these are available from 1819 onwards and depict health expenditures that increased from slightly below 100.000fl in 1819 to 139324fl in 1831/32 and finally 163500fl in 1861/62.[40] Hence, vaccination institutes accounted for less than 0.5% of total health spending.

The numbers do not only compare favorably with Baden's budget, but also with the costs of the decentralized system in Wurttemberg. In the latter, peasants were paid a prime of 2 fl for reporting cowpox among their cattle. Once a case was reported, the district health official had to generate vaccine by transmitting the animal lymph to a human vaccinee, a process that had to be repeated several times. If that operation was successful, the owner of the infected animal would be awarded an additional prime of 2 fl. The accruing travel costs of the vaccinator were founded by the state at a rate of 3fl. 30kr per day. In sum, obtaining a single dose of fresh vaccine would come at a cost of 11fl. After the introduction of the prime in the late 1820s, the

[39] GLA 236-16034 (Sanitary Commission)
[40] Verhandlungen der 2. Kammer der Badischen Ständeversammlung, iss. 157 (1830); Statistik der Inneren Verwaltung des Großherzogtums Baden, various issues 1819-1862

yearly average of reported cases was 30, six of which lead to a successful transfer of animal lymph to human recipients. In 1861/62, when the system had reached a mature state, an average of 35 cases was reported, but again, the number of successful transmissions remained at merely 12. As a result, the sole procurement of vaccine cost the Wurttemberg state between 282 fl. (average 1828-31) and 339 fl. (average 1861/62), which is equal to 56% and 67% of the costs Baden encountered for maintaining its four vaccination institutes. [41] More importantly, these numbers turn positively unfavorable if the following factors are taken into consideration: First, the process was less plannable than Badens's chain of human-to-human vaccination organized by the institutes. And second, the duty to check on reported cowpox cases increased the workload of Wurttemberg's few publicly employed physicians who sought to bypass this duty whenever possible. A district doctor summarized this lack of commitment (which frequently translated into a dangerous lack of vaccine!) in the sarcastic remark that he was tired of "examining the warts on the udders of the cows in the village".[42]

6.3. Saving lives:

The ultimate aim of public health policies is saving lives. In other words: if the picture drawn by the previous indicators was correct, Baden should have attained lower death and infection rates from midcentury onwards, that is, from the point in time when implementation strategies started became important for immunization success. Indeed, corresponding evidence exists and points into this direction: Comparing long term mortality averages from the 1850s and 1860s, it turns out that smallpox mortality was roughly 1 per 16000 in Baden and 1 per 11000 in Wurttemberg in the period 1858-68. (Deutsche Klinik (1875), p.79). While these results are encouraging, it would be naive to take them at face value. One reason for this is that in our observation period these statistics were not standardized nor collected on an annual basis. In addition, differential diagnostics were imprecise such that many cases of smallpox might have passed unnoticed.

Seeing the weaknesses of official death counts, a more valid indicator of the two vaccination systems' effectiveness is the excess mortality rate. Excess mortality counts the number of deaths that would not have occurred if a certain event (e.g. an epidemic) had not happened. Thus, excess mortality compares the observed total mortality of a certain year and country with the mortality rate one would expect if conditions had been normal. The advantage of this

[41] Corresponding bills from doctors and peasants' primes can be found in StAL, F177-II-387
[42] StAL, F177-II-387, letter of the Amtsarzt of Neeresheim, October 13th 1829

approach is that each country is its own point of reference such that country-fixed effects do not bias the estimation. If the vaccination system in Baden had not just been better accepted but also been more effective in buffering the impact of smallpox, excess mortality in epidemic years should have been significantly lower than in Wurttemberg. Moreover, the effect should be noticeable from mid-century onwards - that is from the point in time when the prevention externality grew and the systems began to diverge - and it shoud disappear or decline after 1874 when vaccination was harmonized at the national level.

In current studies, the standard approach to measure excess mortality takes weekly or monthly data of epidemic and non-epidemic years. Death rates which exceed the non-epidemic average are then classified as excess mortality. Whereas this approach is viable today, it is not for historical contexts because weekly and monthly mortality counts do not exist for the 19th century. The highest frequency data we have are annual mortality tables published in the two states' administrative statistics[43] from the 1860s to the 1890s. Moreover, towards the end of this period Baden and Wurttemberg started their demographic transition. Hence, their mortality rates did not fluctuate about a stable mean but experienced a secular decline. Accordingly, the average of previous years will be higher than the true "normal" death rate. To avoid that the estimated excess mortality is skewed downwards it is therefore necessary to control for a negative time-trend. Taking these factors into consideration, I estimated the following model of excess mortality from smallpox:

$$ExcessMort_i = \beta_1 epidemic_i + \beta_2 Baden\_epidemic_i + \beta_3 cbr_i + \beta_4 Baden\_cbr_i + \beta_5 Baden_i + \beta_6 year + \varepsilon_i$$

ExcessMort is the difference between observed mortality in year i and the long-term average number of annual deaths per 1000 inhabitants. *Year* controls for the time effect of the demographic transition and *Baden* is a dummy which is 1 for Baden and zero for Wurttemberg. The next independent variable, *epidemic*, is binary and takes the value of 1 in years where smallpox mortality was at least 3 times its long-term mean.[44] Besides these two, I included the variable *cbr* which captures the crude birth rate of the corresponding year and country. The underlying intuition is that high infant mortality might have inflated mortality in years with high birth rates independent of smallpox prevalence. Since our purpose is to assess

[43] The corresponding periodicals are: Statistik der Inneren Verwaltung des Großherzogtums Baden, Statistisches Jahrbuch für das Land Baden, Württembergische Jahrbücher für Statistik und Landeskunde

[44] Corresponding evidence on outbreaks is from Cless(1875), Imperial Health Office (Kaiserliches Gesundheitsamt), Beiträge zur Beurteilung des Nutzens der Schutzpockenimpfung nebst Mitteilungen über Maßregeln zur Beschaffung untadeliger Tierlymphe, Berlin, 1888, Jahresbericht über die Leistungen und Fortschritte in der gesamten Medizin, vol. 7, 1870 (2nd. Part from page 278 onwards)

the relative capacity of Baden's vaccination system to prevent death from smallpox, the most important variable of the model is the interaction term *Baden_epidemic*. If Baden really outperformed Wurttemberg in terms of limiting mortality, the interaction should be negative and significant. Whether this is the case can be checked in the below table of the regression results. Note that all results are estimated with heteroscedasticity robust and small-sample adjusted standard errors. Moreover, I tested for potential auto-correlation in the mortality series. Since both the standard Durbin Watson statistic and the Breusch Godfrey test for higher order serial correlation returned insignificant values, bias from this source seems negligible in our analysis.[45]

Dependent Variable: ExcessMort				
Variable	**Coef.**	**Robust Std. Err.**	**t**	**P>t**
epidemic	**2,173**	**0,804**	**2,700**	**0,010**
Baden_epidemic	**-3,302**	**1,256**	**-2,630**	**0,012**
cbr	**0,537**	**0,076**	**7,100**	**0,000**
Baden_cbr	**0,071**	**0,016**	**4,320**	**0,000**
Baden	**4.686**	**6,128**	**0,760**	
year	**-0,023**	**0,044**	**-0,530**	**0,597**
_cons	**19,950**	**8,416**	**0,400**	**0,814**
Observations	**52**	**Prob>F**	**0.000**	
Adj. R^2	**0.601**			

As expected, *cbr* and – more importantly – *epidemic* are statistically significant and positive. Specifically, the coefficient of *epidemic* indicates that mortality was approximately 2.1 per 1000 higher in smallpox years. Moreover, *Baden_epidemic* is negative as one would expect based on the favorable documentary evidence presented before. Moreover, the size of the estimated coefficient is considerable – suggesting that excess mortality was roughly 3.3 per 1000 smaller in Baden than in Wurttemberg. This is remarkable because Wurttemberg experienced major smallpox outbreaks in the 1860s, that is, at the same time when the 4th cholera pandemic hit Europe. Thus, due to the generally elevated mortality levels, excess mortality from smallpox in Wurttemberg might have been hidden by the fact that Baden's

[45] The Durbin Watson statistic was in the range of 1.9 to 2.1. The lowest p-value of the Breusch-Godfrey test was 0.25 and hence far off any conventional level of significance.

deaths were also higher than normal due to colera. The true effect of the different vaccination strategies might therefore have been even higher.

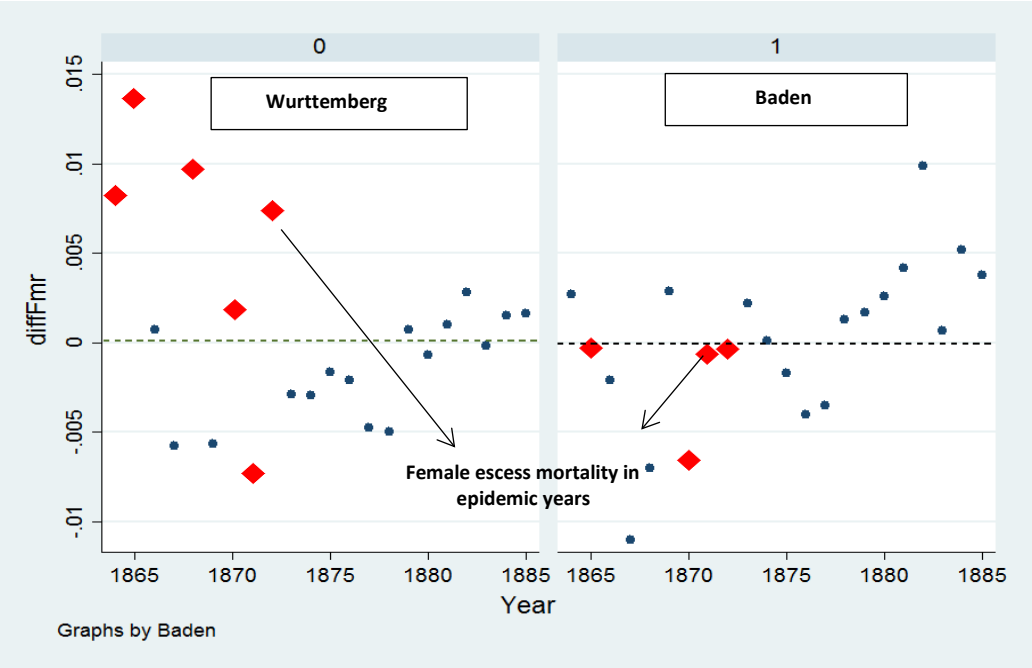
We can address this problem and corroborate the previous results based on a second more specific indicator. This is possible because although primary vaccination was mandatory in Baden and Wurttemberg alike, revaccination of the general population was not. Only young males were obliged to get vaccinated when they started their mandatory military service. As a result, the male population was ceteris paribus better protected than women because revaccination increased resilience against a potential smallpox infection. In years with low smallpox prevalence, this difference should have had no effect on the relative mortality of men and women. Yet, when an epidemic stroke, it ought to have tilted the survival balance in favor of men and discriminate against women. This effect could only be mitigated under conditions like the ones contemporary observers attested Baden's vaccination system: General acceptance of vaccination such that voluntary revaccination of teenage girls was widespread and low costs which allowed parents of all social strata to have their children immunized. Hence, if Baden's smallpox policy was really more efficient than Wurttemberg's, epidemic outbreaks should have had a weaker impact on the gender gap of mortality in Baden than in Wurttemberg. To see whether the historical mortality rates followed this pattern, I estimated the following econometric model:

$$DiffFMMort_i = \beta_1 epidemic_i + \beta_2 Baden\_epidemic_i + \beta_3 cbr_i + \beta_4 Baden\_cbr_i + \beta_5 Baden_i + \beta_6 year + \varepsilon_i$$

Diff-FM-Mort is the difference between the average female/male mortality ratio in country j and the actual mortality ratio in year i and country j. Epidemic is a dummy which as before takes the value 1 for a smallpox year and 0 otherwise. Equally unchanged I maintained the binary control for Baden and an interaction term *Baden_epidemic* which accounts for country specific effects of smallpox. In addition, I kept the control variables year and *cbr*. This was necessary because neonatal mortality was strongly biased towards male infants in historical populations - an effect which was *not* offset by increased maternal mortality. Thus, high birth rates not only affected overall mortality, but also the gender composition. In particular, elevated neonatal mortality of males arguably reduced the female/male mortality ratio in years with high birth rates. Like epidemic, *cbr* was also interacted with Baden to allow for country specific effects. The results of the econometric analysis are displayed below. Just as in the previous model, all significance levels are computed using robust, small sample adjusted standard errors.

Dependent Variable: Diff-FM-mort				
Variable	Coef.	Robust Std. Err.	t	P>t
epidemic	0,0063	0,0031	2,34	0,03
Baden_epidemic	-0,0103	0,0033	-2,19	0,03
cbr	-0,0005	0,0002	-2,07	0,05
Baden_cbr	2.32e-07	0,0000	0,01	1,00
Baden	0,0043	0,1357	0,02	0,71
year	0,0002	0,0002	1,18	0,25
_cons	-0,3438	0,3159	-1,09	0,28
Observations	44			
Adj. R^2	0.290	Prob>F	0.001	

The estimated coefficients confirm what has been found before. Thus, whereas epidemic increases female mortality in both countries, the effect is significantly weaker in Baden as shown by the negative interaction term. Interestingly, the more specific indicator *Diff_FM_Mort* reaches statistical significance and indicates that Baden's female mortality was approximately 1 percent smaller in epidemic years than Wurttemberg's. In other words: When a indicator is considered which reacts more sensitively to smallpox than the simple excess mortality rate, the advantage of Baden increases from 3.3 per 1000 to approximately 1 per 100. As shown in the graphical representation below, the econometric analysis therefore supports the archival evidence: Better implementation of seemingly identical laws allowed Baden to protect its population more securely from smallpox than Wurttemberg. Accordingly women were at no higher risk to die in smallpox years (red) than in ordinary years in Baden, whereas smallpox caused significant female excess mortality in Wurttemberg.



7. Conclusion:

Fighting off infectious diseases like smallpox or Covid19 is so hard because it requires qualities, humans are notoriously underendowed with: patience and altruism. Acting against our strictly personal benefit is necessary because prevention creates positive externalities. And patience is indispensable because unpleasant restrictions like quarantines or mass vaccination need time to produce results. So far, Covid19 has successfully played on our weaknesses. Yet, the present paper has shown that it will be possible to contain the pandemic if epidemiological policies are optimally timed and backed by an efficient institutional framework. To make this argument, the paper has studied how smallpox passed from devastating economic and social life to being effectively controlled through vaccination. This evolution is particularly well documented in the German states of Baden and Wurttemberg which provided the paper with a natural experiment.

History suggests that vaccination is no panacea, but it shows that aggressive infectious diseases can be controlled at relatively low costs. If they sidestep certain obstacles, developing and high-income countries alike therefore stand good chances to rid themselves of Covid19. Taking mathematical epidemiology and the economic theory of externalities as a starting point, the paper has found that success in this battle depends on two inflection points: The first was the moment when initially successful counter-measures reduced prevalence and

caused the prevention externality to grow. The second was when the gap between private and social benefits from prevention was maximized. At this point, rather than the formal legal framework, procedural arrangements which increased incentives for compliance and reduced individual costs of prevention became decisive.

The punchline of this is that neither capping the monetary costs nor applying brute force – i.e. making vaccination compulsory by law – guarantees universal immunization. For, although the laws in Baden and Wurttemberg were virtually identical, their immunization levels diverged. Comparing the two German states, the paper found that Baden tended to outperform Wurttemberg both in terms of measurable health outcomes (immunization coverage and smallpox mortality) and indicators of compliance with the vaccination policy. The major factors behind this success were the standardization of the vaccination system, the centralized and efficient supply of high quality vaccine and support from government appointed and publicly salaried community doctors (*Physici*). Wurttemberg maintained a decentralized prevention system which failed to generate the same scale effects and faced fierce opposition from its citizens and parts of the medical profession.

What insights do these results provide beyond the history of smallpox? To begin with, vaccination against SARS-Covid19 will not necessarily succeed even if it is offered for free and mandated by law. Paradoxically, this risk is higher, the greater the initial impact of vaccination. For, as Baden's and Wurttemberg's struggle with anti-vaccinationism shows, individuals respond more sensitively to non-monetary costs of immunization the faster the growth of the prevention externality. Standardized policies of vaccine proliferation and regular public vaccination campaigns take time and require fixed investments. However, this disadvantage can probably be compensated: The case of Baden shows that implementing a system of regular mass vaccination and aggressively communicating its benefits when high prevalence provides these measures with tail can offset the adverse effect of falling private benefits from prevention. Policies which aim at the general public should therefore be adopted early, at a massive scale and they should be targeted towards groups rather than individuals (e.g. all children in a school, all members of a parish, all inhabitants of a neighborhood, etc.). The reason is that - as long as vaccine safety is beyond doubt - focusing on the collective level generates peer group pressure, habit formation and social learning. Moreover, this approach allows policymakers to tailor communication to specific group characteristics and to disseminate information through popular influencers (teachers, scientists, journalists etc.) - a

feature which, as we have seen, helped Wurttemberg's Jagst district to consistently exceed the country's poor average vaccination rate.

Still, neither legal coercion nor flooding the media with well-intended recommendations will suffice to end the current pandemic. The reason is that the historical case has also flashed out that the availability of skilled vaccinators and the commitment of doctors were central for the functioning of the system at its mature stage. Lack of skilled workforce has been recognized by the European Commission [46] as a major bottleneck for comprehensive anti-Covid19 immunization. The case of Wurttemberg has shown that this corner cannot be cut by maximizing the number of vaccinators at the expense of professional standards and control. For, by granting the right to vaccinate to any licensed doctor or surgeon, the country made the process hard to supervise and rendered safe, effective and properly documented vaccination a target rather than a reality. Baden opted for a different - in hindsight superior - strategy. The country delegated vaccination exclusively to academically trained doctors who were public officials. This status came with close administrative control but also with a measure of financial security. Hence, Baden's vaccinating doctors were less dependent on the goodwill of patients and more likely to insist publicly on the lancet's enormous epidemiological value. This was particularly important when the prevention externality widened and the anti-vaccination movement spread to the wealthy middle-class.

In sum, the experience of smallpox therefore suggests that countries can improve their odds to defeat Covid19 if they strengthen their public health systems and seek to ensure universal access to primary care. This way, both monetary- and "shoeleathercosts" of vaccination can be minimized and information can be channeled directly to patients to alleviate fears and fight misinformation. Moreover, strong public health institutions are central for the coordinated deployment and storage of vaccines, for the protection and supervision of health workers and - finally - for the documentation of vaccine success and the detection of undesired side-effects.

Taken together all these measures obey to a simple economic rationale: If viruses thrive when humans are selfish and myopic, our institutions and procedures must make vaccination not just the "right" - i.e. the socially optimal - but also the simplest and cheapest choice.

[46] https://ec.europa.eu/health/sites/health/files/vaccination/docs/2020_strategies_deployment_en.pdf

Conflict of Interest:

I hereby declare that I have not received any funds from third parties to conduct this research. I am not aware of any conflict of interest.

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Appendix 1: Selected Socio-economic Indicators for Baden and Wurttemberg

Indicator	Baden	Wurttemberg	Sources
Population Density	90.4 per km^2 in 1850	89.4 per km^2 in 1850	Historical GIS database Baden-Württemberg, explanatory notes: https://www.leo-bw.de/media/kgl_atlas/current/delivered/pdf/HABW_12_2_4.pdf
Crude Mortality per 1000	27.1 (=average 1850-1880)	31.0 (=average 1850-1880)	Statistik der Inneren Verwaltung des Großherzogtums Baden, Statistisches Jahrbuch für das Land Baden, Württembergische Jahrbücher für Statistik und Landeskunde
Crude Birth Rate per 1000	37.7 (=average 1850-1880)	41.1 (=average 1850-1880)	Statistik der Inneren Verwaltung des Großherzogtums Baden, Statistisches Jahrbuch für das Land Baden, Württembergische Jahrbücher für Statistik und Landeskunde
Average Height of Recruits	163.5 cm (birth cohorts 1820-1830)	163 cm (birth cohorts 1815-1819)	A. Ecker, Zur Statistik der Körpergrösse im Großherzogtum Baden, in: Archiv für Anthropologie, vol. 9, 1876, pp. 257-60; Ewert, Ulf Christian, The biological standard of living on the decline: episodes from Germany during early industrialisation, in: European Review of Economic History, vol. 10, issue 1, 2006, pp. 51-88.
Per-capita Income	562 (=constant 1904 prices)	591 (=constant 1904 prices)	A. Jeck, Wachstum und Verteilung des Volkseinkommens. Untersuchungen und Materialien zur Entwicklung der Einkommensverteilung in Deutschland 1870 – 1913, Tübingen 1970

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