Physician density and infant mortality: A semiparametric analysis of the returns to health care provision

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Abstract

This paper investigates the effect of physicians on infant mortality, stillbirths and the incidence of common childhood diseases. We construct a new panel data set covering German municipalities from 1928 to 1936 based on historical sources. The endogeneity of health care supply is addressed by using the expulsion of Jewish physicians from health insurance schemes by the Nazi government in 1933 as a source of exogenous variation in regional physician density. The results indicate substantial mortality effects due to changes in physician density. One additional physician per 1,000 of population reduces infant mortality by 23% and stillbirths by 16%. We find similar negative effects for gastrointestinal diseases and the incidence of measles, influenza and bronchitis. To investigate diminishing returns to health care provision, we develop a semiparametric control function approach. Our results indicate that the marginal returns to physicians are highly nonlinear and decreasing.

Keywords: infant mortality, physicians, health care supply, childhood diseases, semiparametric IV

JEL classification: I10, I18, N34

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1 Introduction

The reduction in infant mortality among industrialized countries since the 19th century constitutes an unprecedented development in human history. Infant mortality rates had been consistently high for a long time. Estimates for Europe in the middle ages suggest an infant death rate of about 30%, essentially the same level as in the mid-19th century (Dyer 1989, Shahar 1990, Mitchell 2013). At the beginning of the demographic transition in the early 1900s, death rates started to decrease sharply. In Germany in 1900, 225 children out of 1,000 born died within their first year of life. In 1950, it was less than 60 and in 2015, the rate was down to 3.1, a decrease of more than 98% over a century (cf. Figure 1). In contrast to this, infant mortality rates still remain high in many developing economies. Of 4.5 million infant deaths worldwide in 2015, 99% occurred in developing countries (You et al. 2015).

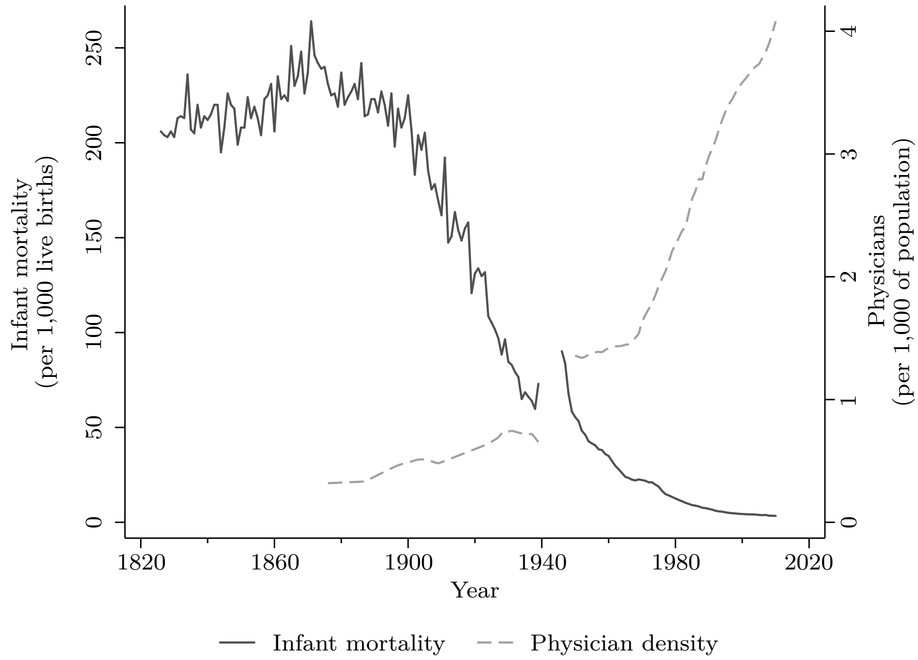
The mortality decline in developed economies coincides with other important public health developments. Standards of living, nutrition and public hygiene started improving at the end of the 19th century and public health care supply was expanded substantially (Loudon 1991, Cutler et al. 2006, Frohman and Brook 2006). Between 1900 and 1950, the ratio of physicans per population increased more than twofold (cf. Figure 1). Physicians provide pre- and postnatal care, attend birth, administer medication and encourage health-related behavior and compliance with hygienic standards (cf. Stanton and Clemens 1987, Fewtrell et al. 2005, Terza et al. 2008).

In this paper, we establish a causal link between physician coverage and public health by tracing exogenous shocks to the supply of physicians. Although cross-country studies have established a positive correlation between physician density and health, there is a lack of causal evidence how much an increase in the supply of physicians improves health outcomes. The supply of physicians is endogenous to health care demand and a simple comparison of health outcomes between regions will lead to biased estimates. However, training physicians is costly and knowing whether an additional physician affects public health is important for health policy.

To identify the causal effect of physicians on mortality, we utilize a series of discriminatory policies introduced in Germany in 1933 which banned Jews from public positions and severely limited the professional activity of Jewish physicians. Jews were disproportionately overrepresented in the medical profession, with about 17% of physicians considered Jewish by the Nazi definition in 1933 (Kröner 1989). The distribution of the Jewish population varies across German municipalities, providing ample variation in treatment intensity. Our analysis relies on a large sample of administrative data covering the period from 1928 to 1936. Detailed information on causes of death and disease incidence allows us to examine specifically which medical conditions physicians can influence.

To pinpoint where improving coverage is most effective, we provide non-parametric

Figure 1: Infant mortality in Germany, 1826–2010



Notes: The graphs shows the historical development of infant mortality and physician density in German territories between 1826–2014. Infant mortality is measured as the number of children dying within the first year of life per 1,000 live births. Sources: Data is collected from Gehrmann (2012), Statistisches Reichsamt (1884–1940) and Statistisches Bundesamt (1944-2015) [Federal statistical office].

estimates of the marginal returns to physicians. In doing so, we evaluate the hypothesis of diminishing returns to health care provision. Improving medical care may be especially effective in regions where coverage is sparse; whereas increasing supply in regions where levels are already high may increase luxury health care consumption, but do little to improve vital health outcomes. For this purpose, we develop a semiparametric instrumental variables (IV) estimation approach. We combine a control function approach with a partially linear model in the spirit of Robinson (1988) and Baltagi and Li (2002) to derive a non-parametric estimate of the dose-response function.

Our findings suggest that one additional doctor per 1,000 of population reduces infant mortality by about 18 cases per 1,000 live births. This corresponds to about a 23% reduction in baseline mortality. In our sample, one additional doctor is approximately equivalent to doubling the coverage ratio. Moreover, our results show that reductions occur for deaths from inflammatory bowel diseases and stillbirths, which are among the main causes for mortality in developing countries today. We also find mortality reductions for viral diseases like measles, influenza and bronchitis. Fatalities due to premature birth and congenital issues, for which medical treatment is difficult, are unaffected. Using the semiparametric IV estimation method, we demonstrate that mortality effects are highly nonlinear and disappear after a coverage ratio of about two physicians per 1,000 of population.

Previous papers investigating the importance of physicians in reducing child and infant mortality rates in both economics and medical science have yielded mixed results (see Andrews et al. 2008, Kuruvilla et al. 2014). Most studies rely on cross-country comparisons, often focusing on single cross-sections (e.g. Kim and Moody 1992, Hertz et al. 1994, Anand and Bärnighausen 2004). Some papers use a panel data approach to control for the influence of time-invariant unobservable factors (e.g. Farahani et al. 2009, Bhargava et al. 2011, Chauvet et al. 2013). The results from these studies vary. Some find a negative relationship between physician density and mortality, but many results are inconclusive. Micro data evidence is limited. Frankenberg (1995) examines the impact of access to health facilities and personnel on infant and child mortality in Indonesia using village-level data and a fixed effects approach and finds that a maternity clinic reduces the odds of infant mortality by 15% and an additional doctor by 1.7%. Lavy et al. (1996) provide evidence that increased supply of health staff and drugs can improve child health in rural areas in Ghana. They also evaluate the impact of health infrastructure on child outcomes, but are unable to find conclusive evidence. Aakvik and Holmås (2006) use a dynamic panel approach to estimate the effect of general practitioner density on total mortality in Norwegian municipalities from 1986 to 2001, but do not find a significant relationship. This mirrors the results of other studies looking at health outcomes more broadly which rely on simple linear regression approaches (e.g. Newhouse and Friedlander 1980).

A limiting factor of these studies is their inability to account for time-varying endogenous changes in the supply of physicians.[1] Moreover, sample sizes are often small and the data quality questionable (Hill et al. 2007, Farahani et al. 2009). Most low- and middle-income countries do not have well-functioning vital registration systems and estimates of the infant mortality rate often rely on a mixture of sources and reporting systems. Our paper addresses both of these issues. Using exogenous variation in the supply of physicians due to discriminatory measures allows us to obtain a causal estimate of the effect of an additional physician on infant mortality. Furthermore, as population statistics and vital registration systems were already well established in Germany in the early 20th century, we can rely on a comparatively large administrative dataset of German municipalities.

The remainder of the paper is structured as follows: section 2 provides the institutional background for our analysis, section 3 reviews the data, section 4 discusses our empirical strategy, section 5 presents our results and section 6 concludes.

[1] Other studies allow for a causal interpretation, but do not focus on the immediate relationship between physicians and infant health. Most paper focus on more specific treatments when estimating the effect of care utilization intensity on infant health, e.g. specialized hospital care for newborns (Almond et al. 2010, Almond and Doyle 2011). Other authors evaluate health effects in the general context of supply- or demand-side financing reforms (e.g. Gruber et al. 2014) or the introduction of health insurance schemes like Medicaid (e.g. Goodman-Bacon 2018).

2 Institutional background

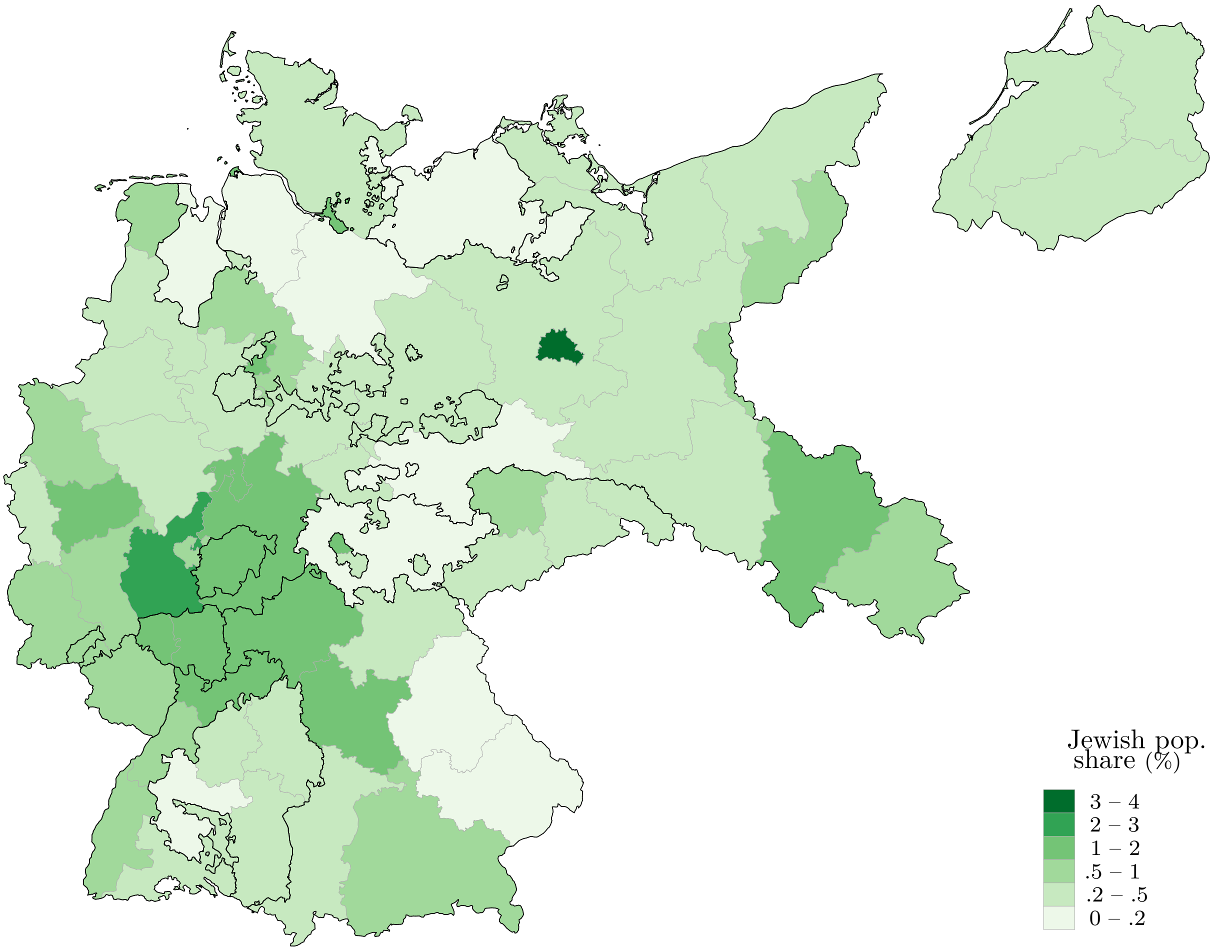
The 1933 German census registered 499,682 residents of Jewish faith. Overall, this constituted only a small share of the then total German population of about 65 Million, 0.77%. Since the census registered only citizens who confessed to the Jewish faith, this measure constitutes a lower bound for the share of the population considered Jewish by the extended definition introduced by the National Socialist Party. The Jewish population was distributed across all German regions, but concentrated in urban regions with over 70% of Jews residing in larger cities compared to 30% of the entire population. Figure 2 shows the spatial distribution of the Jewish population across German districts. The relatively smallest Jewish communities are located in rural areas in the north and the south. The largest Jewish communities lived in Frankfurt am Main (4.71%), Berlin (3.78%) and Breslau (3.23%). However, even though Jews constituted only a small part of the total population, they were disproportionately overrepresented in skilled occupations, especially in the medical profession. 10.9% of all doctors were of Jewish faith and approximately 17% were considered Jewish by the Nazis. In some municipalities, these figures where considerably higher. In Berlin, around 52% of all doctors were considered non-Aryan in 1933 (Kröner 1989).

Shortly after seizing power in 1933, the Nazi government introduced discriminatory policies that limited the professional activity of Jewish citizens. On April 7, 1933, the NSDAP passed the *Gesetz zur Wiederherstellung des Berufsbeamtentums* [Law for the restoration of the professional civil services]. The law decreed that civil servants of non-Aryan descent or with dubious past political activity could not be trusted to be loyal to the state and were to be placed in retirement effective immediately.[2] An implementation decree further specified that it was sufficient to have one Jewish grandparent to be considered of non-Aryan descent. Exceptions were granted to those who had been employed since before August 1, 1914 or who had served in the First World War. However, this privilege could be declared exempt if a person was judged to be politically unreliable, an exception that was invoked frequently. This meant that non-Aryan doctors were forced into retirement at universities, publicly funded hospitals and all public medical institutions. By May 6, 1933 two executive orders extended the law to ordinary state employees, forcing resident physicians out of work as well.

On April 22, the law was followed by the *Verordnung über die Zulassung von Ärzten zur Tätigkeit bei den Krankenkassen* [Decree on the accreditation of doctors for health insurance funds], which withdrew the licence to practice for the compulsory health insurance fund

[2]The repercussions of the discriminatory laws and the subsequent dismissal of Jewish scientists from German universities have been investigated in a series of papers by Fabian Waldinger, who examines the consequences for educational outcomes (Waldinger 2010), academic productivity and peer effects (Waldinger 2012), the role of human and physical capital for the creation of scientific knowledge (Waldinger 2016) and the link between German Jewish Emigrés and US inventions (Moser et al. 2014).

Figure 2: Jewish population share in German regions in 1933



Notes: The graph shows the Jewish population share in 1933 across German sub-state administrative districts (*Regierungsbezirke*). District borders are shaded grey. State borders (*Länder*) are colored in black.

from Jewish and other non-Aryan physicians.[3] The same exceptions as above applied, but could again be declared void if the physician could be shown to have been active as a communist. The term communist was interpreted broadly and could also include social democratic physicians (Kröner 1989, Leibfried and Tennstedt 1980). Shortly after, an agreement between the association of German doctors and the association of private health insurance providers from July 1933 declared that bills from non-Aryan doctors were only reimbursed if they were subject to the exception clause or if the patient himself was of non-Aryan descent (Böhle 2003). This effectively expulsed Jewish doctors from private health insurances as well.

Finally, a directive by the *Reichsärztekommissar* [Federal commissioner of physicians] from August 1933 specified that doctors of Aryan and non-Aryan descent were no longer allowed to stand-in for one another nor to refer patients to each other or to consult

[3]Health insurance was compulsory for all employees with an income of less than 3,600 Reichsmark. The average income in 1927 was 1,742 Reichsmark (Klingenberger 2001).

(Beddies et al. 2014). This also applied to non-Aryan physicians who profited from the exception clause and was especially harmful for specialists, who depended on referrals. According to the *Reichsvertretung der Juden in Deutschland* [Representation of German Jews], the directive rendered it virtually impossible for non-Aryan physicians to work in private hospitals and made the license for compulsory health insurance practice often worthless for those who still had one (Kröner 1989). The only remaining options for Jewish doctors were to emigrate, to find work in a Jewish hospital or to go into private practice. However, Klingenberger (2001) estimates that in 1930 there were only around 600,000 private patients in Germany, compared to a total population of around 65 million. This suggests that private practice could only provide a means of existence for a limited number of physicians and would be associated with a severe reduction in income. Considering their future in Germany, many Jewish physicians opted to emigrate (Kröner 1989). The Jewish physicians who remained in Germany finally lost their medical licence in September 1938. At this point, preparations for war were already under way. A year later, on September 1, 1939, Germany invaded Poland, initiating World War II.

3 Data

The dataset is assembled from a variety of historical sources. The population and mortality figures are taken from the *Reichsgesundheitsblatt* [Health bulletin] (eds. 1927–1936), a yearly statistical publication by the health ministry of the German Reich. The data covers all municipalities with a population above 15,000. It tracks yearly changes in the municipal population. Available information includes total population figures, the number of births, marriages, and deaths. Mortality information is available in detailed categories in accordance with the International List of Causes of Death (ILCD-4, approximately corresponding to the International Classification of Diseases ICD-10 in use since 1990). The disease categories were expanded and partially redefined in 1930, restricting the coverage period for some variables. Panel attrition is less than 3% since the population threshold of 15,000 was not adhered to strictly. We restrict the sample to those municipalities with full coverage for a balanced panel (this choice is inconsequential for the results). Around 7% of the municipalities in our sample merge or split during the observation period. The affected municipalities have been harmonized to the municipal structure in place in 1933.

The main analysis focuses on infant mortality, i.e. the number of children dying within the first year after birth (excluding stillbirths) and the number of stillbirths. We also look at a few specific causes of death for infants that are listed in the data, inflammatory bowel diseases and premature birth or congenital defects. Additional outcomes are the population disease incidence figures for a number of common childhood diseases. While mortality is an extreme health outcome, it is historically well-measured and unambiguous indicator of poor health that is not subject to varying measurement standards. The analysis uses incidence rates to track mortality effects. Infant mortality is measured as deaths in year t per 1,000 live births in $t-1$, stillbirths are recorded per 1,000 births in $t-1$ and disease mortality incidence per 1,000 of population in $t-1$. Similarly, the physician coverage ratio is expressed as physicians per 1,000 of population in $t-1$. These expressions are commonly used in epidemiology and allow comparisons with other work. Relative incidence is the more interesting target parameter in this context and also helps to abstract from trends in birth rates. We use lagged values for the reference population instead of current ones to contain endogenous feedback effects.

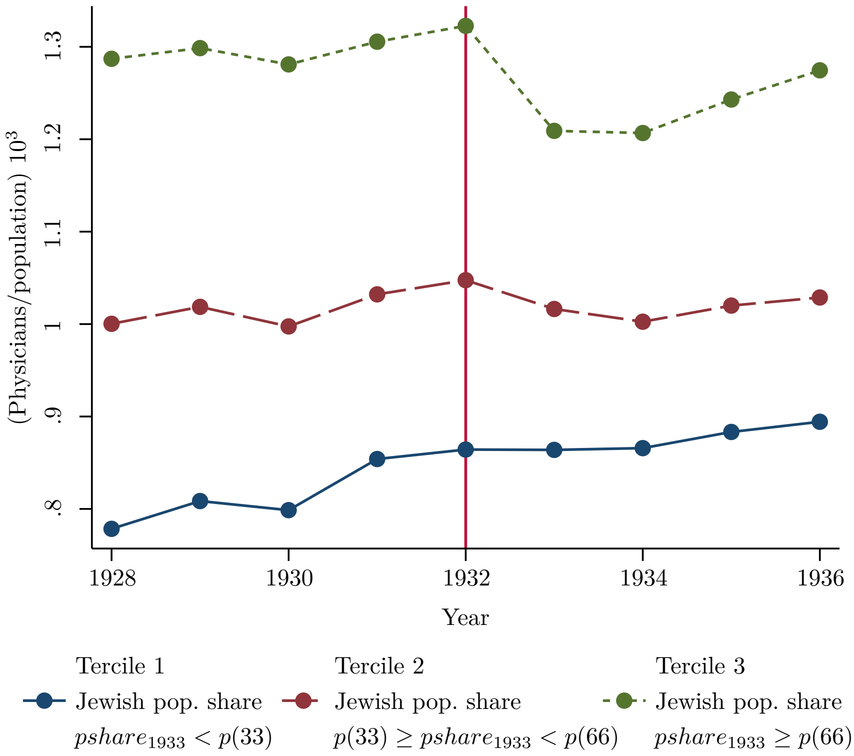
In addition, the unadjusted mortality figure distributions feature overdispersion and a long right tail typical for count data. Rescaling reduces skewness and alleviates these issues to some degree. Figure A4 compares the original and the scaled distributions for selected variables and illustrates that in many cases, anchoring mortality incidence to a reference population leads to a distribution that is approximately normal. For some variables, especially those with a comparatively large share of zero observations, the scaled distribution remains right-skewed. We address this issue in section 5.4.

Information about the number of physicians is taken from the *Reichs-Medizinal-Kalender/Verzeichnis der deutschen Ärzte und Heilanstalten* [Register of German physicians and hospitals], a yearly publication listing physicians in Germany for each municipality. The register includes the full name, address, specialization and the year the medical licence was acquired. The publication also tracks physicians who cease practising and émigrés between years. We observe yearly emigration of physicians for every municipality. Prior to 1933 we observe only 145 physicians who emigrate. From 1933 to 1936 this number increases to over 2700 physicians. Considering the names and the migration destinations of the émigrés, it is evident that the majority are of Jewish heritage.

Moreover, we construct two alternative measures of the treatment intensity in 1933. Editions of the Reichs-Medizinal-Kalender after 1936 explicitly tag Jewish physicians (considered Jewish by the extended definition). From this, we construct a measure of Jewish physicians per municipality. Furthermore, we know the exact amount of people of Jewish faith in each municipality from the official population census conducted in 1933, just when the discriminatory measures where implemented. We use both the number of Jewish physicians remaining after 1936 and the local Jewish population in 1933 to proxy for the number of Jewish physicians expelled in 1933.

The final sample is a balanced panel comprising 2,853 observations in 317 municipalities between 1928–1936. Our dataset covers 29,168,080 people in 1933, about 45% of the total German population at the time. By construction, the sample is selected on larger, more populous and urban municipalities. Descriptive statistics are given in Table A1 in the appendix. Although persons of Jewish faith number only 0.6% of the population, Jewish physicians account for about 7% of all physicians in our sample. This differs slightly from the 10% reported to be of Jewish faith in official aggregate statistics due to the timing of

Figure 3: Trends in physician coverage



Notes: The graphs shows the development of the number of registered physicians per 1,000 of population between 1928 and 1936. Plotted are yearly mean values partitioned by Terciles of the Jewish population share in 1933.

the measurement and the difference in the definition of who is considered Jewish. For every 1,000 live births, about 75 children die before reaching one year of age. The physician coverage ratio is approximately 1 per 1,000 of population.

To illustrate the dynamics in the data, Figure 3 depicts trends in the municipal physician coverage ratio per 1,000 of population over time, partitioned by terciles of the municipal Jewish population share in 1933. The graph shows a distinct drop in the number of physicians in 1933 in municipalities with a higher share of Jewish residents. Importantly, this type of analysis does not reflect our empirical approach. We do not rely on partitioning into groups, except for illustration. Since municipalities are affected to varying degrees in our setting, partitioning into groups is not sensible. In the analysis, we explicitly rely on time-varying treatment intensity and policy exposure measures and refrain from ad-hoc partitioning of continuous measures.

The use of time-varying intensity measures is also important for other reasons. From the graph, it is evident that the number of physicians recovers after 1934. Although the discriminatory policies cause a decline in the number of licensed physicians, they do not prevent endogenous locational sorting of physicians into municipalities with vacancies and higher demand for medical services in the following years. Especially for younger physicians who just finished their residency, the situation constitutes a good opportunity to open up practice in municipalities where more positions are left vacant. Historical evidence suggests that in later years, vacant positions and licenses for the public health insurance fund were awarded preferentially to young SA- and NSDAP-physicians (Leibfried and Tennstedt 1980).

4 Empirical strategy

4.1 Identification and linear model

Identifying the effect of physician coverage on health outcomes is hampered by a series of selection problems. Most importantly, health care supply is endogenous to health care demand. Physicians tend to locate in places where their services are in demand, leading to a positive association between sickness prevalence and health care services. The endogenous locational choice of practice has long been recognized. The geographic distribution of physicians has and continues to receive a lot of attention, from economics, medical science and policy makers alike (e.g. Cooper et al. 1977, Newhouse et al. 1982, Fruen and Cantwell 1982).

Moreover, certain market failures have been documented in health care markets which strengthen the positive relation between health care supply and demand. Supplier-induced demand arises from the information asymmetry between physicians and patients and leads to the oversupply of medical services in excess of individuals' medical needs (Newhouse 1970). Persistent small area variation can also lead to a positive association between health care and health (Wennberg and Gittelsohn 1973). Since the 1970s, an extensive literature has documented real world occurrences of both phenomenons in many segments of the health care sector.

In addition, physicians are aware of local competition and vacancies when opening practice. Our main data source, a register of physicians in Germany first published in 1880, served as a work of reference that could also help ascertain the market when deciding where to open practice. Today, specialized consultancy services and a wealth of information regarding local market demand and coverage ratios are available to help physicians decide where to locate.

These persistent features of health care markets make it notoriously difficult to identify the degree to which changes in health care coverage influence the health of the population. Consider a regression equation of mortality incidence y on physician supply s in municipality $i = 1, \ldots, N$ in year $t = 1, \ldots, T$,

$$y_{it} = \beta s_{it} + \eta_i + \delta_t + \epsilon_{it} \ , \tag{1}$$

where η_i and δ_t are municipality and year fixed effects and $T \ll N$. Estimates for β_1 from this equation are typically biased upwards due to positive selection.

We are using exogenous shocks to the supply of physicians to identify the causal effect of physician coverage on population mortality incidence. The 1933 law causes a drop in the number of registered physicians (cf. Figure 3). However, a naive before-after comparison is insufficient to eliminate endogeneity, since it does not account for the intensity with which a municipality is affected and the dynamic selection into vacancies in the following years. The one-time change does not prevent physicians from subsequently sorting into municipalities where their services are needed and offer large potential rewards. In the empirical analysis, we are using an instrumental variables approach to trace exogenous variation in health care. Our main specification uses the variation in the number of registered physicians induced by the emigration of Jewish physicians. Specifically, we are augmenting the structural equation (1) with the first stage regression

$$s_{it} = \alpha z_{it} + \psi_i + \theta_t + \nu_{it} \ , \tag{2}$$

where z_{it} measures the yearly emigration of physicians per municipality, i.e. number of physicians who give up their residency and move to a foreign country. We estimate the system by two-stage least squares.

This is our preferred specification, as the time-variant instrument emigration also accounts for dynamic selection (cf. Figure 3), and the fact that health effects may only materialize with some delay. Nevertheless, we extend our analysis by using our two proxies for the number of Jewish physicians expelled in 1933 as alternative instruments, i.e. the number of Jewish physicians remaining in 1936 and the local Jewish population in 1933. In this case, the instrument z_{it} is equal to the interaction between the respective proxy for Jewish physicians and the period indicator $\mathbb{1}\{t_i \geq 1933\}$. Hence, these measures only proxy for treatment intensity at a single point in time and therefore offer less identifying variation compared to our preferred specification. Although both variables are only imperfect proxies, when using them as instruments, the measurement error is not going to affect the estimates if the propensity to remain in 1936 or to become a physician is constant within the Jewish population. More general, the measurement error in the proxy will not confound the estimates unless it is correlated with municipal unobservable factors that are related to health.

The assumptions implicit to this estimation procedure are discussed in turn. Monotonicity (or in the linear case, homogeneity in the form of a common α), i.e. that emigration of physicians can only influence the total number of physicians in one direction or not at all is likely fulfilled: Outmigration reduces the number of registered physicians, unless excess migration of physicians from other municipalities would immediately overcompensate for the reduction. Another possibility is that the market were fully saturated and non-registered German physicians working in other professions now overcompensate for the reduction due to emigration. These scenarios do not seem plausible. Relevance is an empirical issue. Emigration of physicians naturally reduces the count of registered doctors. First stage results show a significant negative effect that is statistically indistinguishable from a one-to-one relation. The exclusion restriction is that changes in the propensity to migrate (or in the level of Jewish physicians) only influence population health by affecting the number of physicians. This means migration must be unrelated to other time-variant factors that influence mortality. A valid concern is that a violation may be caused by non-random assignment of the instrument, i.e. if the spatial distribution of Jewish physicians is correlated with other features that impact population health in a way that is not absorbed by municipality or time fixed effects. Jewish communities were more prevalent in certain regions within Germany and also within metropolitan areas. Should health and population dynamics differ substantially between more and less populous or urbanized regions, the exclusion restriction may be violated such that $\mathrm{E}[z_{it}\epsilon_{it}] \neq 0$. This concern is partly alleviated by the fact that our sample is already preselected on more populous, urban municipalities. Nevertheless, we address the issue of population dynamics in detail in the robustness checks and show that our results are unlikely to be driven by these factors.

4.2 Semiparametric model

A simple linear specification as given in (1) may not fully capture the mortality reduction of physician coverage. Diminishing returns matter for vital outcomes like mortality. The effect of physicians is most likely nonlinear, as an additional doctor in a region with sparse coverage can prevent more infant deaths compared to an additional doctor in a saturated region. After a certain coverage ratio has been reached, mortality effects are likely to taper off. While morbidity effects may persist, systematic fatality reductions beyond a lower bound of medically difficult cases are unlikely. We investigate the hypothesis of diminishing returns by employing a semiparametric estimation approach using a partially linear model. We combine the Baltagi and Li (2002) semiparametric fixed-effects estimator with a control function (e.g. Heckman and Robb 1985) to derive a flexible estimate of the effect of physicians on infant mortality.

Consider a general panel model of the form

$$y_{it} = f(s_{it}) + \eta_i + \epsilon_{it} \ . \tag{3}$$

$$s_{it} = g(z_{it}) + \psi_i + \nu_{it} \tag{4}$$

Time fixed effects are dropped for notational convenience. To control for the endogeneity in the physician supply s_{it}, we add the control function $\hat{\nu}_{it}$ for s_{it} obtained from (2) to the model as a linear term,

$$y_{it} = f(s_{it}) + \hat{\nu}_{it}\rho + \eta_i + \zeta_{it} \ . \tag{5}$$

The control function approach assumes that the correlation between the structural error ϵ_{it} and the first stage error ν_{it} can be described as a linear relationship $\epsilon_{it} = \nu_{it}\rho + \zeta_{it}$ with $\mathrm{E}[\nu_{it}\zeta_{it}] = 0$. We require $(\epsilon_{it}, \nu_{it}) \perp\!\!\!\perp z$. The endogenous variation in s_{it} is corrected using the estimated control function $\hat{\nu}_{it}$.

We estimate this model using the first difference approach described in Baltagi and Li (2002), as the conventional Robinson (1988) double residual estimator cannot accommodate the municipality-specific intercepts. To eliminate the fixed effects, take first differences of (5) with respect to time,

$$\Delta y_{it} = \Big\{ f(s_{it}) - f(s_{it-1}) \Big\} + \Delta\hat{\nu}_{it}\rho + \Delta\zeta_{it} \ . \tag{6}$$

Baltagi and Li (2002) show that $f(s)$ can be approximated by a power series $p^k(s)$, and $\Big\{ f(s_{it}) - f(s_{it-1}) \Big\}$ by $\Big\{ p^k(s_{it}) - p^k(s_{it-1}) \Big\} \gamma$. Equation (6) can be rewritten as

$$\Delta y_{it} = \Big\{ p^k(s_{it}) - p^k(s_{it-1}) \Big\} \gamma + \Delta\hat{\nu}_{it}\rho + \Delta\zeta_{it} \ . \tag{7}$$

We use cubic B-splines to approximate $f(s_{it})$ and $f(s_{it-1})$. Having estimated the series terms, γ and ρ can be estimated with least squares from (7). The estimates can be used to fit the fixed effects $\hat{\eta}_i$. Together, the estimates can be used to get the partialled-out residuals

$$\hat{u}_{it} = y_{it} - \hat{\nu}_{it}\hat{\rho} - \hat{\eta}_i = f(s_{it}) + \zeta_{it} \ . \tag{8}$$

We then fit $f(\cdot)$ by regressing the residual $\hat{u}_{it}$ on s_{it} using local polynomial regression. The first derivative of the obtained function with respect to s is the desired marginal effect, $\mathrm{d}y/\mathrm{d}s = \mathrm{d}f(s)/\mathrm{d}s$.

5 Results

5.1 Infant mortality and stillbirths

The main results are presented in Table 1. The reported coefficients can be interpreted as the effect on mortality if the coverage ratio increases by one additional physician per 1,000 people. Since the mean coverage ratio in the sample is 1.05, the estimates also approximately indicate the effect of doubling the coverage ratio.

The first panel in Table 1 shows the results when directly regressing health outcomes

Table 1: Mortality estimates

	(1)	(2)	(3)	(4)
	Infant mortality			
	Total	Infl. bowel diseases	Prem. birth, cong. debility	Stillbirths
	OLS			
# of registered physicians	2.71	−0.10	−0.43	−2.85
	(3.61)	(0.93)	(3.35)	(2.12)
	IV: Emigration			
# of registered physicians	−18.79***	−7.11***	−2.48	−8.42***
	(4.17)	(0.98)	(5.09)	(2.24)
First stage F-stat.	29.70	29.70	36.18	36.18
	IV: Jewish physicians in 1933			
# of registered physicians	−13.62**	−4.18***	−0.92	−6.11***
	(6.41)	(1.20)	(4.02)	(1.64)
First stage F-stat.	15.60	15.60	17.79	17.79
	IV: Jewish population in 1933			
# of registered physicians	−13.10**	−4.41***	−0.29	−6.88***
	(6.39)	(1.14)	(4.31)	(1.78)
First stage F-stat.	14.89	14.89	17.05	17.05
Year fixed effects	✓	✓	✓	✓
Municipality fixed effects	✓	✓	✓	✓
N municipalities	317	317	317	317
N	2853	2853	1902	1902

Notes: Infant mortality variables are measured per thousand live births in $t-1$, stillbirths per thousand total births in $t-1$. Registered physicians are measured per thousand of population in $t-1$. Included instruments are a full set of year and municipality dummies. Excluded instruments are given in the respective paragraph header if applicable. Standard errors clustered at the municipality level given in parentheses. *, **, *** denote significance at the 0.1, 0.05, 0.01 level respectively.

on physician coverage. For any outcome, the effect is indistinguishable from zero. The next panel shows our preferred specification, instrumenting the physician coverage ratio with the emigration figures. Looking at column (1), we find that one additional physician reduces overall infant mortality by about 18 cases per 1,000 live births. The average yearly infant mortality prior to 1933 is about 80. In relative terms, doubling the coverage ratio reduces infant mortality by about 23%. Regarding stillbirths, our results in column (4) show that an additional physician reduces the number of stillbirths by about 8 cases. In relative terms this corresponds to a decrease of about 27% (prior to 1933 there were on average 30 stillbirths per 1,000 births per municipality).

For infant deaths caused by inflammatory bowel diseases (ulcerative colitis, enteritis, diarrhea or other ulcerations of intestines), a prominent cause of death for young children, especially in conditions of sub-standard hygiene and contaminated drinking water, we also find a significant negative effect. This effect is also large in relative terms, presumably since

Table 2: Disease incidence

	Incidence rate by cause of death per 1,000 of population						
	Viral diseases			Bacterial diseases			
	Bronchitis	Influenza	Measles	Pneumonia	Diphteria	Scarlet fever	Typhoid fever
# of registered Physicians	−0.047* (0.028)	−0.045** (0.018)	−0.013*** (0.005)	−0.325 (0.213)	0.008 (0.018)	−0.001 (0.005)	−0.003 (0.003)
Year FE	✓	✓	✓	✓	✓	✓	✓
Municipality FE	✓	✓	✓	✓	✓	✓	✓
First stage F-stat.	36.18	29.70	29.70	29.70	29.70	29.70	29.70
N municipalities	317	317	317	317	317	317	317
N	1902	2853	2853	2853	2853	2853	2853

Notes: All dependent variables given as incidence rates per thousand of population in $t-1$. Registered physicians are measured per thousand of population in $t-1$. Included instruments are a full set of year and municipality dummies. Excluded instrument is yearly emigration of physicians. Standard errors clustered at the municipality level given in parentheses. *, **, *** denote significance at the 0.1, 0.05, 0.01 level respectively.

gastrointestinal diseases were already known as a prominent cause of infant mortality in the 1930s. In contrast, the estimates in column (3) show that increasing the physician coverage ratio has no effect on infants dying from premature birth or congenital defects. This is an intuitive result. Medical complications arising from premature birth and congenital debility are notoriously difficult to treat and account almost completely for the remaining cases of infant mortality in developed economies today. Note that the number of observations for this set of regressions is lower due to a shorter coverage period in the data.

Comparing the results using emigration as the instrument (second panel) to the alternative instruments (panels three and four), results are very similar. All estimates are significant and results are comparable in magnitude, albeit consistently slightly smaller. This may be due to the fact that the instruments are time invariant (after 1933), and although they factor in the magnitude of the policy change in 1933, they cannot account for the selection of physicians into municipalities with vacancies in later years.

5.2 Disease incidence

We extend our analysis to mortality rates from a set of diseases that, although not limited to, are a common cause of death for children. All variables are stated as population incidence per 1,000 persons. Bronchitis, diphteria, influenza and pneumonia are among the more frequent causes of death with between one to eight deaths per 10,000 individuals.

The results for disease incidence are given in Table 2. We find that one additional physician can decrease mortality due to bronchitis by about 4.7 cases per 100,000. The effect for influenza mortality is of comparable magnitude with a reduction of 4.5 cases. For measles, we find that incidence is reduced by about 4.5 cases per 100,000. Given the comparatively low baseline incidence, these effects are substantial. We cannot reject a zero effect for pneumonia, diphteria, scarlet fever and typhoid fever.

Interestingly, we find a negative effect only for viral diseases. In contrast, the diseases for which we do not find any effect are all bacterial. The exception is pneumonia, a disease which can be caused by both viral and bacterial mechanisms (and for which the p-value is 0.12). Viral diseases cannot be treated by antibiotics and with the exception of measles, vaccinations for the viral diseases we consider are not widespread and do not offer lasting protection. Treatment for these diseases typically consists of non-steroidal anti-inflammatory drugs like Aspirin to reduce fever and inflammation. These drugs were known and readily available in pharmacies in the 1930s. In addition to this, physicians recommend sufficient rest, fluids and nutrition.

5.3 Nonlinear mortality effects

Results for the semiparametric analysis are presented in Figure 4. Panel (a) plots an estimate of the conditional mean function using the partialled-out residuals. This function provides an estimate of the average residual infant mortality by number of physicians after controlling for endogenous selection of physicians, municipality and time fixed effects. Panel (b) shows the estimated first derivative of this function, i.e. the marginal effect of increasing the physician coverage ratio on infant mortality.

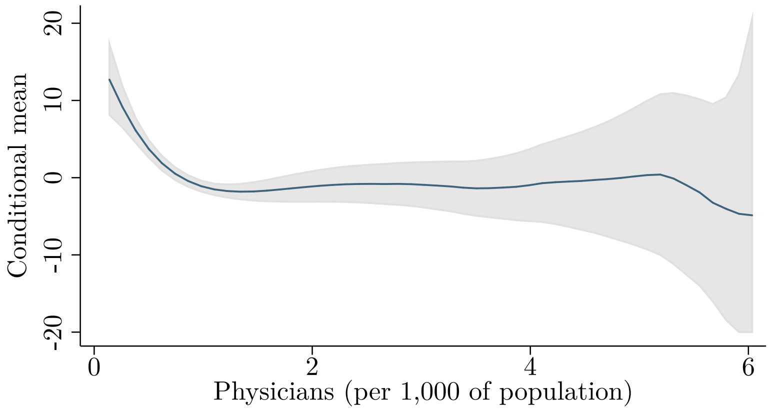
We find that physicians can strongly reduce infant mortality when coverage is sparse, but that the effect declines as coverage increases. Importantly, mortality effects are restricted to a specific interval of low coverage. After the coverage ratio reaches about 1.8 physicians per 1,000 of population, mortality effects subside. The estimated marginal effect is indistinguishable from zero for higher coverage ratios, in a region where the data is still dense (cf. panel (c)). Physicians most likely still influence morbidity, general health and quality of life in the population. However, after the population coverage ratio exceeds two physicians per 1,000, any remaining cases of infant mortality are unrelated to physician coverage and most likely medically difficult cases. Our results mirror the development of the industrialized world. In most developed countries, infant mortality rates have barely changed since the 1980s, when coverage ratios reached a comparable magnitude (cf. section A.1).

5.4 Robustness and specification checks

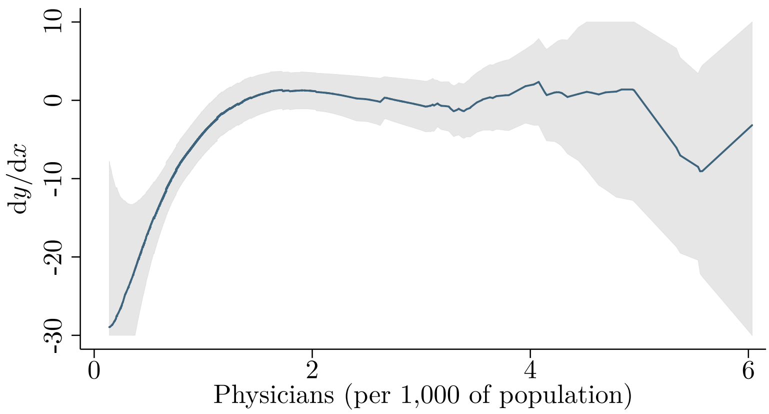
We conduct a series of robustness checks to show that our results are valid and not driven by alternative mechanisms or the choice of a specific model. The discussion in section 4 raises the point that a violation of the exclusion restriction could occur if districts with a higher rate of Jewish physicians evolve differently over time in a way that is related to mortality. For example, if the municipal population structure changes differentially for

Figure 4: Semiparametric analysis

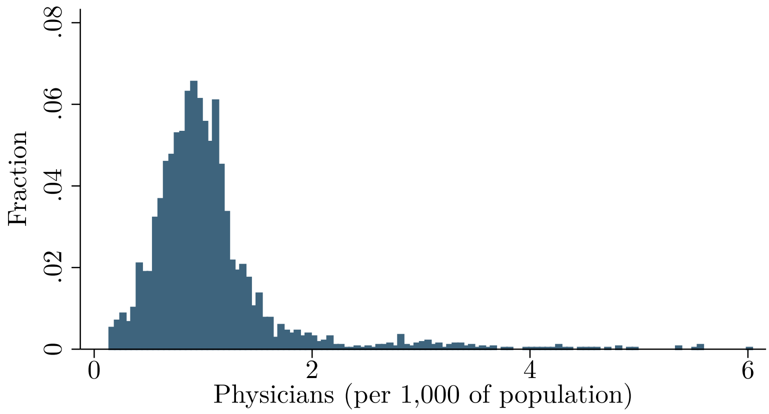
(a) Nonparametric fit



(b) Marginal effect



(c) Density



Notes: Figure (a) plots the partialled-out residuals of the infant mortality rate by physician density; accounting for the control function of the physician coverage ratio, individual and time fixed effects following the framework outlined by Baltagi and Li (2002). Observations with values outside the scale of the y-axis have been cropped from the scatterplot to improve exposition. The nonparametric fit was generated using local polynomial regression with a polynomial of degree 4, an Epanechnikov kernel function and a bandwidth of 1.3 chosen by Silverman's rule-of-thumb. Figure (b) plots the marginal effects by physician density, i.e. the first derivative of the above function for each level of the independent variable. Shaded in grey in both plots are the 95% confidence intervals. Figure (c) plots the distribution of the physician density to better illustrate sparse regions in the support.

different levels of the instrument, population dynamics could also differ over time. Since we are restricting the outcome to mortality figures, any potential dynamic confounding mechanism will necessarily manifest in a municipality's population dynamics. To address this issue, we replicate the main results from Table 1 in Table A3 in the appendix, adding the logarithm of population and population growth in $t-1$ as covariates to control for population dynamics. The results replicate those in Table 1 almost exactly. In fact, precision improves for some of the estimates. The findings are robust to the inclusion of higher order polynomials as well. In addition, changes in population health may not occur instantaneously, but only with slight delay. We have tested this extensively, and our results are replicated almost exactly with a variety of alternative lag structures in the treatment variable.

An alternative mechanism that could explain our findings can be constructed if higher mortality is restricted to Jewish families. In that case, mortality effects may simply be caused by other discriminatory measures instead of the reduced quality of health care. Unfortunately, we are unable to distinguish mortality by population groups. However, it is extremely unlikely that the sizeable mortality effects are restricted to Jewish communities alone because of their disproportionately small population share. We test for this by repeating the analysis after dropping the 20% of municipalities with the most Jewish residents from our sample. Results remain qualitatively unchanged. Regarding other discriminatory measures, while the general environment grew considerably more hostile towards Jewish people after 1933, they still retained their citizenship status and full health insurance. Beginning in 1936, the *Nürnberger Gesetze* limited Jewish citizenship and marriage rights. After 1936, when preparations for war began, further policies essentially removed Jews' citizenship rights gradually and targeted discriminatory measures against anybody with Jewish heritage intensified substantially. Following the events of the *Novemberpogrome* in 1938, Nazi politics escalated from discrimination to systematic persecution, deracination and dispossession. Mass arrests without charges or proceedings commenced. The war started in 1939, the Holocaust began shortly after. For these reasons, we do not include data after 1936 in our analysis. The results are also robust to whether the year 1936 is included in the analysis or not.

Another concern is substitution, i.e. that health care demand is satisfied by visiting out-of-municipality physicians. If this behavior were to occur, it would likely bias our results towards zero. However, we believe that such bias is absent or marginal at best. The municipalities we consider are sufficiently large such that outside substitution is likely to be negligible in comparison. In our data, we only consider mortality of individuals registered within the municipality in question. From the limited vital statistics for children of outside residents we have, we cannot discern any noticeable trend in the regions were there are few Jewish physicians.

As discussed in sections 3 and 4, the distribution of some of the dependent variables raises the concern that the simple linear model may not be appropriate. We repeat our main analysis using an exponential conditional mean model outlined in subsection A.2. This type of model provides a straightforward approach for IV estimation in a nonlinear setting using GMM. Exponential models also offer intuitive interpretation due to constant relative effects. Results are given in Table A4.

We choose a simple Poisson fixed effects model for the naive specification (Table A4, first row), which is consistent even if the distribution were misspecified. Comparing the results, all findings from our main analysis carry through. The naive model does not offer conclusive results, suffering from positive selection. Results for the instrumental variable models are extremely similar. For most variables, the relative effects are almost identical to those obtained from the linear specification, indicating that the linear approximation for the mean works relatively well.

A related concern is that all dependent variables are expressed as ratios to describe relative incidence. This is common in the literature on health and development. We believe the advantages of this approach outweigh the disadvantages, meriting its application. The normalization allows for better interpretability and preserves comparability to standard measures used in other studies. As discussed previously, it reduces the distributional skewness of the unscaled count data (cf. Figure A4), improving the viability of standard linear models. However, if the treatment affects the denominator of the dependent variable as well, treatment effects are detected but operate through a different mechanism. To mitigate this concern, all birth and population counts used in the denominator of the dependent variable are lagged by one period to rule out contemporaneous effects. Nevertheless, the results might still be driven by the denominator if there is serial correlation in these variables. We investigate this issue by repeating the main specifications from Table 1 using birth count as the outcome. In all specifications, the effect is either indistinguishable from zero or slightly negative. This implies that even if there were any change in the denominator, it biases the effect towards zero and the mortality effect in the numerator has to offset the effect on the denominator.

6 Discussion and conclusion

We analyze the effect of changes in the physician coverage on infant mortality and disease incidence in the population. Results indicate substantial mortality reductions. Increasing the coverage ratio from one to two physicians per 1,000 of population decreases infant mortality by about 23% relative to the pre-1933 level. We find a similarly large effect for stillbirths. Increasing health care supply also reduces mortality incidence of inflammatory bowel conditions and common viral diseases, specifically measles, influenza and bronchitis. Mortality due to premature births and congenital debility remains unaffected. Medical treatment for these conditions is difficult and they account for the majority of infant mortality in developed economies today. The Nazis' dismissal of Jewish physicians resulted in a 10% drop in the coverage ratio. A simple back-of-the-envelope calculation suggests this lead to more than 2,200 additional infant deaths each year, even in a very conservative scenario and disregarding non-linearities.

In addition, we provide evidence for dimishing marginal returns to health care provision. Our semiparametric estimation approach reveals that the effect of increasing the physician coverage ratio on mortality is highly nonlinear. Mortality reductions are large in regions where coverage is sparse, but decrease quickly when coverage increases. Moreover, they are only present in a narrow coverage region. After a density of about two physicians per 1,000 of population, mortality effects disappear.

This result underscores the importance of basic health care service provision. Our analysis suggests that establishing and maintaining a level of baseline health care coverage is vital to prevent infant mortality and an important complement to other public health policies. In addition, the nonlinear relationship also provides an explanation why studies analysing developed countries like Aakvik and Holmås (2006) fail to detect a significant relation between physician supply and mortality. Variations in physician density in developed countries post 1990 largely occur in regions of the support where physicians have no substantial influence on mortality anymore. Our results are also consistent with a study by Goodman-Bacon (2018), who analyzes the introduction of Medicaid in the 1960s and its effects on infant mortality. Focusing on health insurance coverage, he also finds large reductions in infant mortality driven by permitting at-risk population groups access to health care and relates the infant mortality reductions to improved acute care at birth.

Our analysis focuses on mortality, but health effects are unlikely to be restricted to fatalities. Higher disease mortality is caused by a general increase in disease prevalence among the population. Increased morbidity in an infant age will reduce general well-being and can often lead to prolonged spells of ill-health and lower life expectancy. We are unable to capture morbidity effects with our analysis due to a lack of data, but they most likely exist. Quantifying effects on disease prevalence and morbidity remains a task for future research.

In our model, we implicitly assume that physicians are homogeneous. In practice, physicians are heterogeneous with regard to skills and specialization. Employing a local average treatment effect (Angrist and Imbens 1995) interpretation of our results, we estimate the effect of changes in the physician coverage induced by emigration. Considering that physicians and the effect on mortality may be heterogeneous, our local estimate may not necessarily coincide with the population average treatment effect if the physicians who emigrate are not a random draw from the skill distribution. There is some historical evidence that many pediatricians were Jewish (Seidler 2007). However, the majority of physicians at the time were general practitioners and not clinical specialists. In 1933, 6.2%

of physicians specialized in gynaecology or pediatrics, 24.8% had other specializations. The majority, 67.4%, were general practictioners. To examine this point further would require collecting more data about physicians' specialization, tenure and mode of employment from historical sources. Such data would also allow investigating the mechanism through which our results operate in more detail.

The historical setting of our analysis provides reliable data and a clean policy experiment for identification. Still, it is important to consider possible caveats regarding external validity. We provide a detailed discussion of historical developments and highlight parallels between 20th century Germany and developing countries today in section A.1. In many aspects, historical data provides a sufficient benchmark for some of today's less developed countries. Infant mortality rates and causes of death are comparable. Procedures for treatment of newborns in developing countries do not differ substantially from those employed in Germany in 1930. Recommendations provided by development organizations for the treatment of newborns today are remarkably similar to those historically provided by physician organizations in Germany (cf. Frohman and Brook 2006). Our analysis precedes the discovery of antibiotics, but these do not matter for the treatment of viral diseases. Other relevant medicines were readily available at the time. Moreover, medical technology diffusion is often limited, and the average state of health care provision in many countries is far from the technological frontier. Nevertheless, medical technology has changed and for some diseases, increasing the supply of physicians today will not have the same effect. Since technological progress increases the treatment efficiency of physicians, our estimates can still be reasonably interpreted as a lower bound.

This in mind, the finding that non-linearities matter strongly for health care provision is also generally important for policy design. Developed countries are experiencing rising health care costs and shortages of physicians in rural areas. In light of this, policy makers have adjusted the size of hospital catchment areas or introduced incentive schemes to ensure sufficient regional provision of general practitioners. Our analysis underscores that it is important to get these policies quantitatively right, as the consequences of underprovision may be severe—the costs involved with type-I and type-II errors are not symmetric.

Similarly, it is important to prevent regional shortages and the breakdown of basic service provision resulting from negative supply shocks. As a development policy, training more physicians may not necessarily be the most cost-effective option to improve public health, when improving sanitation and health-related behavior are cheaper (and possibly more effective) alternatives. However, ensuring sufficient access to health care when service provision is low or non-existent is likely to have high rewards. Moreover, in many of the least developed countries, where child mortality and health issues are already grave problems, current physician density ratios are maintained by humanitarian aid and foreign health professionals. This supply is volatile and resources may be withdrawn due to budget reallocation or conflict hazards. Our results emphasize the need to ensure constant provision of basic health care and to establish a sustainable long-term solution.

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Appendix

A.1 Historical context and external validity

This section draws a comparison between infant mortality in developing countries today and Germany in the first half of the 20th century. We show that there are important similarities not only with respect to infant mortality rates and health care supply but also regarding causes of death and treatment measures. Furthermore, we discuss how changes in the quality of health care affect the external validity of our results.

Since the 1950s, infant mortality in many low and middle income countries has decreased substantially. Infant mortality in South Asia, the Middle East and Sub-Saharan Africa has decreased from around 160 infant deaths per 1,000 live births in the 1960s to between 40 and 60 in 2015 (see Figure A1). These changes resemble the development of infant mortality rates in industrialized economies a century ago (e.g. Cutler et al. 2006). In Germany, 207 infant deaths per 1,000 live births were registered in 1990. By 1933, this number had fallen markedly to 77 cases (cf. Figure A1).

Both in developing countries today as well as in 20th Germany, this decrease was mainly driven by a reduction in mortality of infants which had survived the first month. Consequently, the share of neonates in infant deaths has increased by around 10% in middle and low-income countries since 1990 (The World Bank 2016).[4] Similarly, in Germany this share rose from 32% in 1890 to 52% in 1932 (Statistisches Bundesamt 1951).

Similarities are not only present with respect to infant morality rates but extend to the state of health care supply. In 1930, Germany's physician coverage ratio was approximately equal to 0.75 physicians per 1,000 population. This supply density is comparable to many developing countries today. Figure A2 displays physician coverage ratios for major world regions over the last 20 years. The lowest coverage ratio can be observed in Sub-Saharan Africa with less than 0.3 physicians per 1,000 population. Average coverage ratios in the Middle East & Northern Africa as well as South Asia are closer to our sample average of one physician per 1,000 of population.[5] Similar coverage ratios can be observed in many richer African or poorer Asian or Latin American countries, e.g. Bolivia, Pakistan or India.

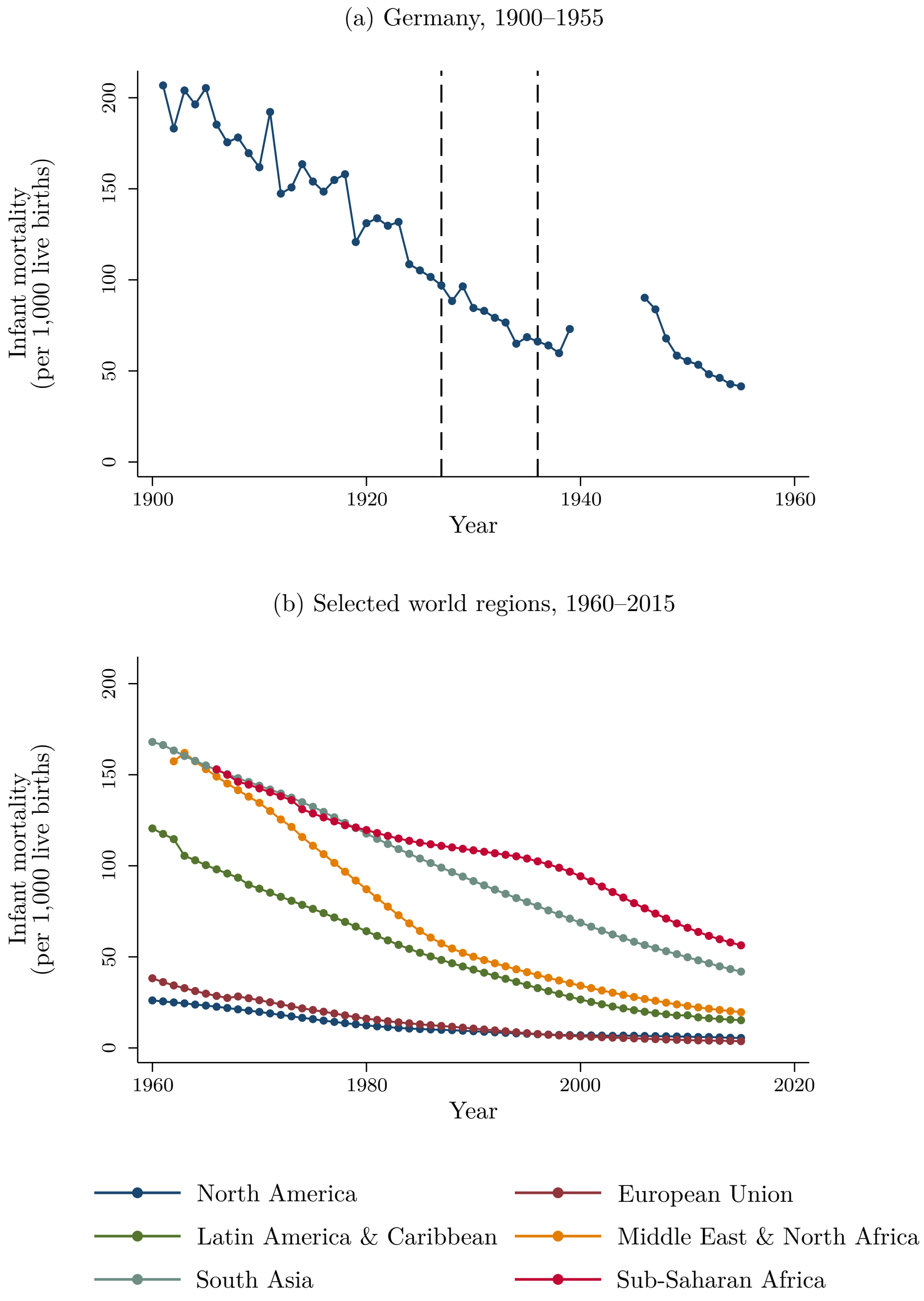
Important parallels also exist regarding the main causes of infant mortality. Neonatal deaths in developing countries today are usually connected to inadequate access to basic medical care at and immediately following birth; the leading causes of neonatal death being infections (36%) such as sepsis, pneumonia, tetanus and diarrhoea, complications surrounding birth (27%) and asphyxia (23%).[6] Low birth weight is often a contributing

[4]Neonatal mortality refers to infants dying within the first 28 days of life (Andrews et al. 2008).

[5]Our sample average is slightly higher than physician density in the whole of Germany as our sample is selected on more populous areas where physician coverage ratios are generally higher.

[6]Around two-thirds of all births in developing countries occur at home and skilled-care is only available in about half of all cases. Postpartum visitation for the newborn is uncommon (Moss et al. 2002).

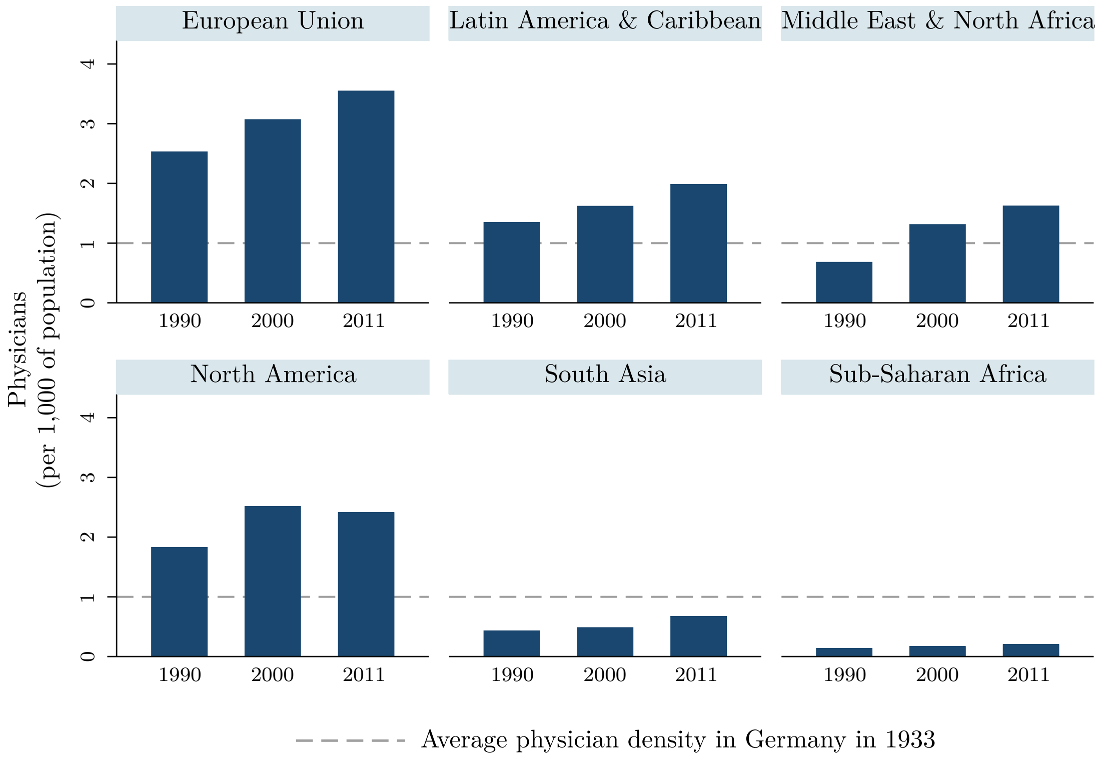
Figure A1: Infant mortality: Historical comparison



Notes: Panel (a) depicts historical infant mortality per 1,000 live births in Germany for the years 1900–1955, panel (b) shows infant mortality estimates per 1,000 live births for selected world regions over the time frame 1960–2015. Source: Statistisches Reichsamt (1900–1940), Statistisches Bundesamt (1945–1955) , World Development Indicators (2016).

factor (Lawn et al. 2005, Andrews et al. 2008). Postneonatal mortality can be attributed to malnutrition, infectious diseases and home environment (Andrews et al. 2008). These causes are similar to those common in developed countries in the early 20th century. The majority of infant deaths then were attributable to deficient pre- and post-natal care, infections and water- and food borne diseases, most commonly respiratory infections and

Figure A2: Physician density across world regions



Notes: Bars depict the average physician density in a region for each available year. The horizontal line is the reference density in Germany in 1933. Source: World Development Indicators (2016).

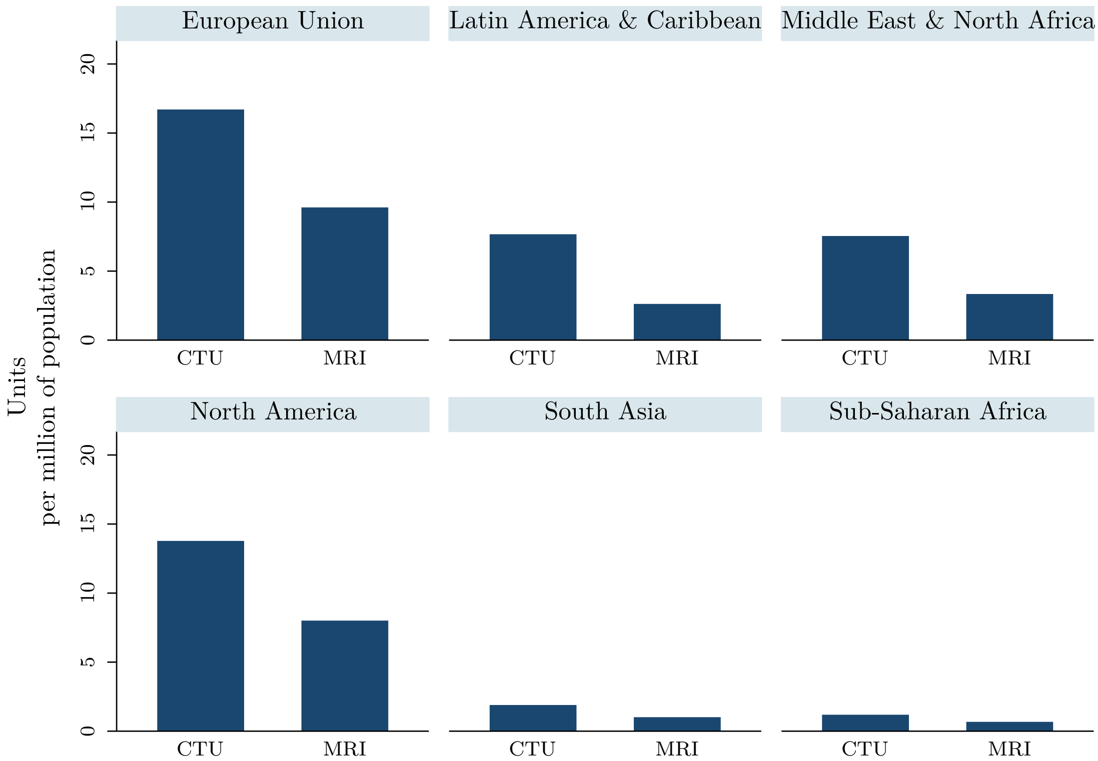
gastrointestinal illnesses (Reichsgesundheitsamt 1926–1945, Cutler et al. 2006). Much like today, these diseases disproportionately affected the poor due to their living and working conditions and insufficient nutrition (Frohman and Brook 2006).

While infant mortality rates, causes of death and coverage ratios are largely comparable between developing regions today and developed countries a century ago, the quality of health care has changed. Medical technology has advanced substantially since 1930. However, medical technology diffusion from developed to developing countries today is very limited. Figure A3 shows prevalence rates of selected medical technologies (magnetic resonance imaging and computed tomography units) across world regions.[7] Especially in countries in South Asia and Sub-Saharan Africa, access to advanced medical technology is very limited. This lack of access is particularly pronounced for rural and poor population segments as medical technology in developing countries is usually concentrated in cities and private hospitals (Malkin 2007, Peters et al. 2008). Moreover, Perry and Malkin (2011) estimate that around 40% of health-care equipment in developing countries is out of service compared to less than 1% in developed countries.[8] Access problems also extend

[7]In the context of infant mortality, data on ultrasound and incubator prevalence would be preferable. However, such data is unavailable. The available evidence suggests that supply is equally poor (Lawn et al. 2010, Ruiz-Peláez et al. 2004).

[8]The lack of a reliable energy supply also constitutes a major hindrance to the employment of medical technology in developing countries. This is especially relevant for therapeutic devices such as neonatal incubators which need to be powered constantly. It is also of consequence for drugs and vaccines who

Figure A3: Medical technology across world regions in 2013



Notes: Bars depict the average prevalence of computed tomography (CTU) and magnetic resonance imaging (MRI) units in a region. Source: World Health Organization, WHO (2016).

to drugs, many of which are not available in low and middle income countries, especially in the public health sector. Even if certain medicines are available in the private sector, their price often substantially exceeds the international reference price which renders them prohibitively costly to large parts of the population (Cameron et al. 2009).

Moreover, much of modern medical technology is of limited relevance for addressing the main causes of infant mortality (e.g. Cutler et al. 2006, Andrews et al. 2008). Simple treatment measures are often sufficient to address many health issues. For example, gastrointestinal diseases are typically treated by ensuring sufficient rest, fluids, nutrition and possibly drugs like Acetaminophen to reduce fever and pain. In the case of birth asphyxia, resuscitation by tactile stimulation or the clearing of upper airway secretions using a covered finger or oral mucus trap is normally sufficient. A need for external ventilation is only given in exceptional circumstances (Moss et al. 2002).

Furthermore, early diagnosis, disease prevention and health practices are relatively more important than treatment after a health problem has fully developed. Physicians play an important role in disease prevention by ensuring health and sanitary practices. Especially for perinatal deaths, pre- and post-natal care practices are a crucial factor (Cutler et al. 2006). For example, proper umbilical core care by physicians using antibacterial agents after birth has been shown to reduce infection of the cord and neonatal sepsis (Moss et al. 2002).

need to be stored at low temperature to remain viable (Howitt et al. 2012).

Late-onset sepsis can be prevented by ensuring a clean caregiving environment. Similarly, a frequent problem in developing countries is hypothermia which affects more than half of all newborns and is associated with increased risk of neonatal infections, acidosis, coagulation defects, respiratory distress syndrome and brain haemorrhage. Neonatal incubators are only needed in extreme cases and hypothermia can generally be prevented by simple measures such as ensuring a warm environment during delivery, early breastfeeding, proper bathing, drying/swaddling and skin-to-skin contact with the mother (Moss et al. 2002).

The importance of health practices is mirrored in modern development economics (e.g. Dupas 2011). A large body of research focuses on how physicians can influence their patients' well-being by encouraging health-related behavior and compliance with hygienic standards (cf. Stanton and Clemens 1987, Fewtrell et al. 2005, Terza et al. 2008). Similarly, propagation of sanitary practices was also the leading sentiment in health policy in the early 20th century (Frohman and Brook 2006). The germ theory of disease was already well established at the time and the importance of a sanitary environment for the prevention of diseases was understood. In fact, many practices recommended by development organizations today are similar to those of physician organizations in Germany during the early 20th century. Examples are the recommendation of exclusive and immediate breastfeeding, in particular for low birth weight newborns and the dissemination of sanitary procedures such as sterilization of water and milk, among others (Moss et al. 2002, Frohman and Brook 2006). In the Weimar Republic propagation of such practices was primarily carried out through infant welfare centers staffed with both physicians, nurses and social workers who provided free medical examinations to both mothers and their infants. Similar to development research today, policy debates focused on how to establish physicians as a recognized authority and improve compliance with their recommendations (Frohman and Brook 2006).

One field where technological progress has been very influential are vaccinations. Although many vaccines were invented during the first half of the 20th century (e.g. Rabies, Plague, Diphteria, Pertussis, Tuberculosis, Tetanus and Yellow Fever) vaccination rates were still relatively low. Immunization rates increased sharply after 1960, and vaccinations for many important childhood diseases were invented afterwards (e.g. Polio, Measles, Mumps, Rubella and Hepatitis B). However, even though morbidity consequences from these diseases are high, historical data suggests that direct mortality due to them was rare even prior to the availability of vaccines (e.g. Cutler et al. 2006). The exception to this is Tuberculosis, which we exclude from the empirical analysis. To illustrate, the measles mortality rate in Germany in 1930 amounted to about 2 cases per 100,000 of population. This figure is comparatively low compared to mortality from Pneumonia (approx. 80 cases per 100,000 of population) or total infant mortality (7,500 per 100,000 live births). Furthermore, even though immunization rates have increased steadily in developing countries over the last 20 years, vaccination is still far from universal especially among poorer population segments (WHO 2016). While vaccines for measles and diphteria have become more widespread, for many of other diseases we consider in the analysis, this is not the case. Vaccines are either unavailable (gastrointestinal diseases, bronchitis, scarlet fever) or uncommon and do not offer long-term protection (influenza, pneumonia, typhoid fever).

Another important development was the discovery of antibiotics. Although penicillin was discovered in 1928, antibiotics were not commercially available for civilians before 1945. However, antibiotics as an antimicrobial drug are not effective against viral diseases such as influenza or bronchitis. Other commonly prescribed drugs were already available and prescribed by physicians in 1930. Simple nonsteroidal anti-inflammatory drugs (e.g. acetylsalicylic acid, introduced as Aspirin by Bayer in 1899) and common pain and fever medications (e.g. Phenacetin, which metabolizes to Paracetamol (Acetaminophen), introduced in 1887) were readily sold in pharmacies (Jeffreys 2008).

In the paper, we analyze historical data from Germany, one of today's developed economies. The historical context may not provide a perfect control case in every dimension, but we believe the health and disease environment is sufficiently similar to allow inferences regarding the effect of care coverage on many traditional causes of infant mortality in present-day developing economies. For those conditions where medical technology has advanced, treatment efficiency is unlikely to deteriorate, in which case estimates can be considered a lower bound of the true effect.

A.2 Exponential model

The model specified in equations (1) and (2) may also be inadequate because of the non-negative nature of the dependent variable. Although rescaling reduces the long right tail in the original count distribution for many variables, this does not work equally well in all cases (cf. Figure A4). Especially when the original variable has generally low incidence that is spread over a comparatively large reference population, the transformed data still resembles typical count data distributions, but is not discrete anymore.

We propose an alternative model specification to address this issue as a robustness check. In addition to the triangular model outlined in subsection 4.1, we estimate an exponential conditional mean model with multiplicative error structure (e.g. Mullahy 1997, Windmeijer and Santos Silva 1997)

$$\begin{aligned} y_{it} &= \exp(\beta s_{it} + \eta_i + \delta_t + \epsilon_{it}) \\ &= \exp(\beta s_{it} + \eta_i + \delta_t)\nu_{it} \\ &= \mu_{it}\nu_{it} \ . \end{aligned} \tag{9}$$

For $\mathrm{E}[y_{it} \mid s_{it}] = \mu_{it}$, the error term in (9) must have a conditional unit mean, i.e. it must be that $\mathrm{E}[\nu_{it} \mid s_{it}] = 1$. This implies that

$$\mathrm{E}\left[\frac{y_{it} - \mu_{it}}{\mu_{it}} \,\middle|\, s_{it}\right] = 0 \ , \tag{10}$$

which will typically be violated due to endogeneity in the number of physicians s_{it}. Instead, we assume a conditional moment condition based on the orthogonal instrument z_i which satisfies

$$\mathrm{E}\left[\frac{y_{it} - \mu_{it}}{\mu_{it}} \,\middle|\, z_{it}\right] = 0 \ . \tag{11}$$

Using moment conditions based on (11), estimation by GMM is straightforward. Even though non-linear, the model features constant relative effects that are intuitive to interpret as incidence rate ratios. The exponentiated coefficients express the multiplicative change in the dependent variable given a unit increase in the independent variable. Since we only specify one conditional moment, the recursive interpretation of equations (1) and (2) is lost. In fact, this limited-information approach requires less assumptions than two-stage least-squares, as we make no assumptions about the distribution of s_{it} given z_{it} (cf. Cameron and Trivedi 2013).

A.3 Tables and Figures

Table A1: Descriptive statistics

	Median	Mean	SD	Min	Max	N	Description
Infant mortality	72.308	75.080	24.076	8.772	229.358	2853	Total yearly municipal mortality rate of children dying before one year of age. Measure per thousand live births in $t-1$.
Inflammatory bowel diseases	3.083	4.529	5.502	0.000	53.640	2853	Yearly municipal mortality rate of children dying from Colitis, Enteritis, diarrhea or other ulceration of intestines before one year of age. Measured per thousand live births in $t-1$.
Premature birth, congenital debility	35.461	37.454	15.233	0.000	99.768	1902	Yearly municipal mortality rate of children dying from congenital debility, malformations or as a consequence of premature birth before one year of age. Measured per thousand live births in $t-1$.
Stillbirths	28.215	29.709	10.917	0.000	80.000	1902	Yearly municipal rate of stillborn children. Measured per thousand births in $t-1$.
Measles	0.000	0.018	0.041	0.000	0.638	2853	Yearly municipal mortality rate due to Measles. Incidence rate measured per thousand of population $t-1$.
Scarlet fever	0.000	0.014	0.028	0.000	0.427	2853	Yearly municipal mortality rate due to Scarlet fever. Incidence rate measured per thousand of population $t-1$.
Diphteria	0.045	0.076	0.108	0.000	1.285	2853	Yearly municipal mortality rate due to Diphteria. Incidence rate measured per thousand of population $t-1$.
Influenza	0.069	0.102	0.114	0.000	1.144	2853	Yearly municipal mortality rate due to Influenza. Incidence rate measured per thousand of population $t-1$.
Bronchitis	0.127	0.153	0.124	0.000	0.966	1902	Yearly municipal mortality rate due to Bronchitis. Incidence rate measured per thousand of population $t-1$.
Pneumonia	0.708	0.746	0.298	0.000	3.119	2853	Yearly municipal mortality rate due to Pneumonia. Incidence rate measured per thousand of population $t-1$.
Typhoid fever	0.000	0.009	0.022	0.000	0.445	2853	Yearly municipal mortality rate due to Typhoid fever. Incidence rate measured per thousand of population $t-1$.
Physicians	0.944	1.048	0.613	0.139	6.034	2853	Registered physicians coverage ratio. Measured per thousand of population in $t-1$.
Jewish physicians, share	5.263	6.930	7.814	0.000	52.602	2853	Share of Jewish physicians over all physicians in percent.
1933 Jewish population	0.156	1.292	9.303	0.001	160.564	2853	Jewish population in 1933 in thousands.
1933 Jewish population, share	0.451	0.629	0.643	0.004	4.713	2853	Share of Jewish population based on 1933 Jewish and total population in percent.
Population	32.004	91.598	270.226	15.192	4339.641	2853	Total municipal population in thousands.

Notes: All statistics are based on the largest estimation sample covering the years 1928–1936. Sources: *Reichsgesundheitsblatt* [Health bulletin] (eds. 1928–1936), Reichsgesundheitsamt [Federal health ministry]. *Volks-, Berufs- und Betriebszählung* [Census] 1933, Statistisches Reichsamt [Federal statistical office]. *Reichsmedizinalkalender – Verzeichnis der deutschen Ärzte und Heilanstalten* [Register of German physicians and hospitals] (eds. 1928-1936), Thieme Verlag.

Table A2: First stage estimates

# of physicians emigrating	−1.149***		
	(0.211)		
# of Jewish physicians in 1933		−0.380***	
		(0.096)	
Jewish population in 1933			−0.004***
			(0.001)
Year FE	✓	✓	✓
Municipality FE	✓	✓	✓
First stage F-stat	29.69	15.60	14.88
N municipalities	317	317	317
N	2853	2853	2853

Notes: First stage estimates for different instrumental variable specifications. The dependent variable is the number of registered physicians per 1,000 of population in $t-1$. Estimates are scaled by 10^3. Included in all specifications are a full set of year and municipality dummies. Standard errors clustered at the municipality level given in parentheses. *, **, *** denote significance at the 0.1, 0.05, 0.01 level respectively.

Table A3: Robustness: Population dynamics

	(1)	(2)	(3)	(4)
	Infant mortality			
	Total	Infl. bowel diseases	Prem. birth, cong. debility	Stillbirths
	OLS			
# of registered physicians	−1.24	−0.62	0.81	−3.00
	(3.63)	(0.93)	(3.66)	(2.24)
ln(population) $(t-1)$	−16.57	−3.24	27.19**	6.46
	(11.67)	(2.69)	(13.15)	(8.59)
Population growth (%, $t-1$)	0.82***	0.09***	0.10	0.24
	(0.13)	(0.04)	(0.23)	(0.15)
	IV: Emigration			
# of registered physicians	−18.34***	−6.75***	−4.26	−8.85***
	(3.54)	(0.99)	(5.02)	(2.22)
ln(population) $(t-1)$	−26.25**	−6.71**	23.33*	2.00
	(11.18)	(2.75)	(13.33)	(7.77)
Population growth (%, $t-1$)	0.93***	0.13***	0.14	0.29**
	(0.13)	(0.04)	(0.23)	(0.14)
First stage F-stat.	32.62	32.62	39.70	39.70
	IV: Jewish physicians in 1933			
# of registered physicians	−12.58**	−3.84***	−2.42	−6.20***
	(5.63)	(1.11)	(4.04)	(1.65)
ln(population) $(t-1)$	−22.99**	−5.06*	24.72*	4.02
	(11.39)	(2.67)	(12.75)	(7.67)
Population growth (%, $t-1$)	0.89***	0.11***	0.13	0.27*
	(0.13)	(0.04)	(0.22)	(0.14)
First stage F-stat.	16.77	16.77	18.97	18.97
	IV: Jewish population in 1933			
# of registered physicians	−12.40**	−4.10***	−1.91	−6.96***
	(5.51)	(1.08)	(4.25)	(1.78)
ln(population) $(t-1)$	−22.88**	−5.21*	25.12**	3.44
	(11.39)	(2.67)	(12.71)	(7.66)
Population growth (%, $t-1$)	0.89***	0.11***	0.12	0.27**
	(0.13)	(0.04)	(0.22)	(0.14)
First stage F-stat.	16.08	16.08	18.02	18.02
Year fixed effects	✓	✓	✓	✓
Municipality fixed effects	✓	✓	✓	✓
N municipalities	317	317	317	317
N	2853	2853	1902	1902

Notes: Infant mortality variables are measured per thousand live births in $t-1$, stillbirths per thousand total births in $t-1$. Registered physicians are measured per thousand of population in $t-1$. Included instruments are a full set of year and municipality dummies. Excluded instruments are given in the respective paragraph header if applicable. Standard errors clustered at the municipality level given in parentheses. *, **, *** denote significance at the 0.1, 0.05, 0.01 level respectively.

Table A4: Exponential model mortality estimates

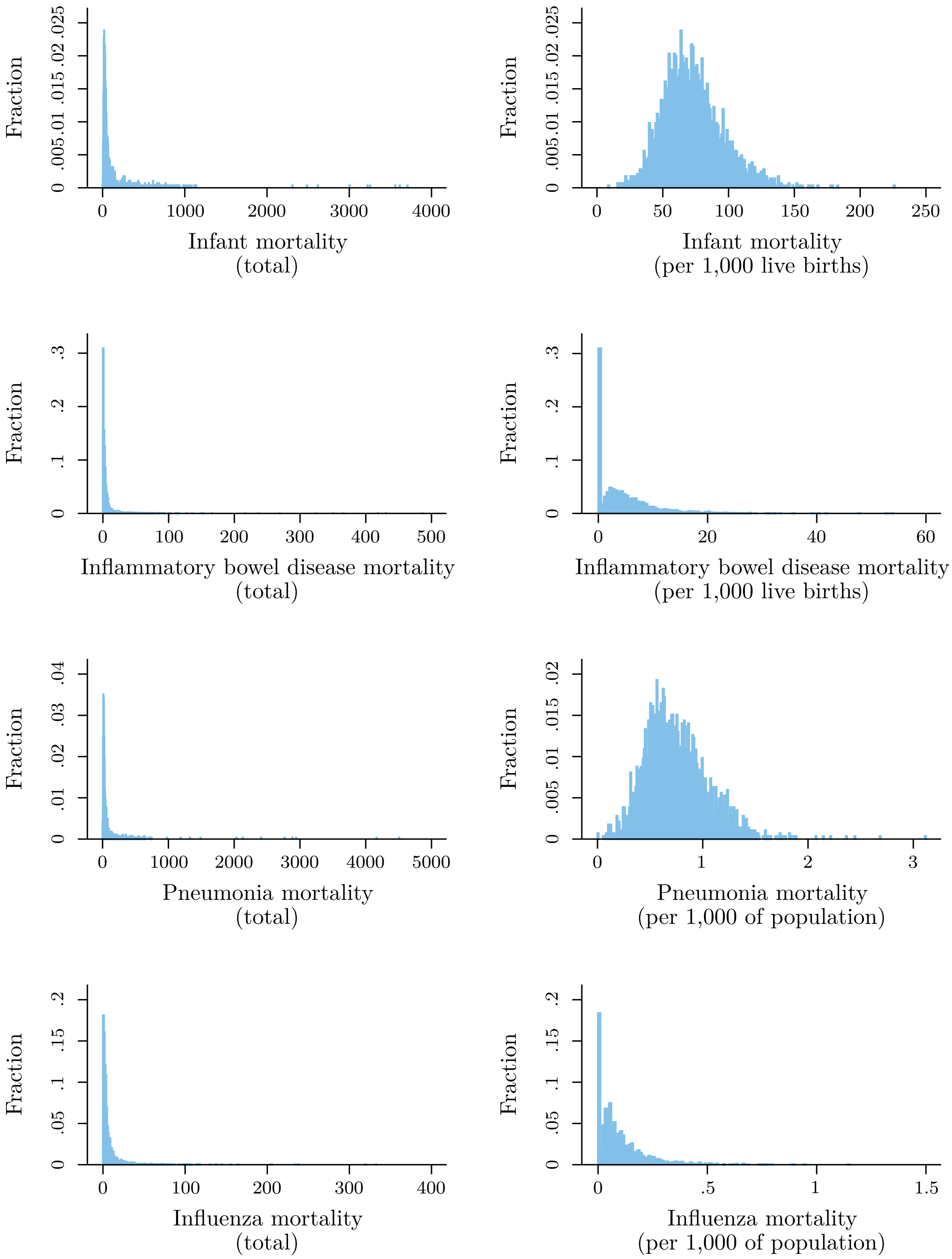
	(1)	(2)	(3)	(4)
	Infant mortality			
	Total	Infl. bowel diseases	Prem. birth, cong. debility	Stillbirths
	Poisson			
# of registered physicians	1.02	0.83	0.96	0.90
	(0.05)	(0.17)	(0.10)	(0.07)
	IV: Emigration			
# of registered physicians	0.77***	0.32***	0.92	0.78***
	(0.04)	(0.09)	(0.12)	(0.06)
	IV: Jewish physicians in 1933			
# of registered physicians	0.83**	0.39***	1.01	0.84***
	(0.06)	(0.10)	(0.13)	(0.05)
	IV: Jewish population in 1933			
# of registered physicians	0.84**	0.38***	1.03	0.82***
	(0.06)	(0.10)	(0.14)	(0.05)
Year fixed effects	✓	✓	✓	✓
Municipality fixed effects	✓	✓	✓	✓
N municipalities	317	317	317	317
N	2853	2853	1902	1902

Notes: Results from exponential model instrumental variable estimation by GMM. Estimates are reported as incidence rate ratios, indicating the multiplicative change in the dependent variable given a unit increase in the physician coverage ratio. The null hypothesis in all tests is that the coefficient takes value one. Infant mortality variables are measured per thousand live births in $t-1$, stillbirths per thousand total births in $t-1$. Registered physicians are measured per thousand of population in $t-1$. Included instruments are a full set of year and municipality dummies. Excluded instruments are given in the respective paragraph header if applicable. Standard errors clustered at the municipality level given in parentheses. *, **, *** denote significance at the 0.1, 0.05, 0.01 level respectively.

Figure A4: Comparison of count and reference-scaled distributions

(a) Raw counts

(b) Per reference population



Notes: Column (a) shows the distribution of the original unscaled counts, column (b) the distribution of the same variables scaled per reference population. Each row depicts the same base variable. All plots are based on the (largest) main estimation sample.