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Environmental and socioeconomic determinants of neonatal mortality in a northern Italian city in the early nineteenth century

Alessio Fornasin[1] · **Laura Rizzi**[1]

Abstract

The research explores the effects of the environment on neonatal mortality in the early nineteenth century, controlling for social and economic factors. Individual data, relative to the resident population of Udine, a city in northeastern Italy, under French domination (1806–1815) have been used. The information collected regards births and deaths within the first month of life and is taken from the Napoleonic civil registers. The spatial distribution of some data within the urban area, heating in the houses where children were born or died, and a time series of temperature levels and corn prices are taken into account. The methodological approach adopted is based on logistic regression models and discrete-time event history analysis. The results point to excess winter neonatal mortality. Neonatal mortality was higher in peripheral areas of the city and in heated houses. A positive relationship between mortality and lower temperatures and corn prices has been found. As to socioeconomic status, peasant families and those of the upper class showed, respectively, the lowest and the highest mortality levels. This was arguably the result of the adoption of different breastfeeding practices.

Keywords Neonatal mortality · Nineteenth century · Cold extremes · Pollution · Housing · Corn prices

Introduction

Environmental factors affect survival at all ages. These factors are rarely the direct cause of death, but, under certain circumstances, they can accelerate mortality in particularly frail people. In the first month of life, environmental factors come out

✉ Alessio Fornasin
  fornasin@uniud.it

  Laura Rizzi
  laura.rizzi@uniud.it

1 Dipartimento Di Scienze Economiche E Statistiche, Università Degli Studi Di Udine, via Tomadini, 30/A - I-33100, Udine (UD), Italy

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in peculiar ways, as a combination of elements that act both before the birth of the baby, i.e., during pregnancy, and in the weeks immediately following birth. Neonatal mortality is defined as the rate between the number of deaths during the first month of life and the number of births. The definition is simple, but only in appearance (Armstrong, 1986). It depends more on biological than on behavioral factors. Neonatal mortality includes many deaths from causes preceding or associated with in utero conditions, like fetal malformation, immaturity, congenital abnormalities, and birth trauma. Neonatal mortality also depends on the mother's health, which, in turn, depends on her nutritional status, on war or epidemic shocks, and on persistent states of economic insecurity. Some of these causes are directly associated with environmental conditions: these include temperatures and housing (Andersson & Bergström, 1998; Bruckner et al., 2014; Catalano et al., 1999).

The effects of external stress factors on preterm deaths seem to affect male babies more, to the extent that there is a bias in the birth sex ratio (Helle et al., 2009). This is a particular issue for premature births where low birth weight represents one of the major risk factors in neonatal mortality (Catalano, 2003; Catalano et al., 2005, 2008; Kemkes, 2006; Rettaroli & Scalone, 2021). Risk factors for neonatal mortality often affect stillbirths as well (Pozzi & Ramiro Fariñas, 2015; Reid, 2001). The death of a newborn baby may be caused by factors such as nutrition, infections, pollution, and accidents. Many environmental factors or "exogenous factors" influence endogenous causes of death. Moreover, these factors, which are related to the social and economic status of families (Hart, 1998; Pozzi & Barona, 2012; Woods, 2009), affect mortality not only at birth and during the weeks afterwards. They bring lasting consequences with permanent effects throughout life (Barker, 1990; Quaranta, 2013).

This study is concerned with neonatal mortality in the pre-transitional period. The literature on environmental factors and neonatal mortality in historical populations has been mainly concerned with temperature. Temperature levels have been commonly and regularly collected at least since the nineteenth century. On the other hand, measures of pollution levels or of housing conditions were rarely collected or were completely unavailable in the 1800s and before. In this study, instead, the availability of wide and detailed datasets for the same territory allows us to take into account some aspects of housing and, indirectly, of pollution. Generally, scholars have used aggregated datasets or individual-level data in small or in confined urban areas. This study, instead, accounts for the whole population of Udine, a small city in northeastern Italy, whose population followed both rural and urban lives. Data are relative to the years 1807–1815, preceding the usual period considered in many studies on this phenomenon. The population of Udine followed typical *ancien régime* socioeconomic and demographic behavior.

The study explores the effects of environmental factors on neonatal mortality, while controlling for their relationships with social and economic factors, like, for instance, the father's occupation or the corn prices. The paper is organized into six sections. After this "Introduction" section, in the "Background" section, the main literature results are evaluated, with both present-day and historical analyses. In the "Context and sources" section, the main demographic and social and economic characteristics of the population living in Udine in the early nineteenth century are set out, together with a list of data sources. Then, in the "Methods"

section, the methods are discussed and, in the "Results of descriptive analysis and models" section, the main results are reported. The "Discussion and conclusions" section is devoted to discussions and conclusions.

Background

Meteorology

Historical investigations on the relationship between mortality and environmental factors are generally devoted to neonatal and infant mortality, which are the age classes most at risk of death for these factors. Studies often consider information on social and economic status too, while acknowledging that environmental effects on mortality are different across social categories. In general, the role of meteorological variables is analyzed with the seasonality of demographic phenomena such as mortality in mind (Breschi & Livi-Bacci, 1997). In this regard, neonatal mortality in Italy is characterized by excess winter mortality (Breschi et al., 2000; Esposito, 2018). Beyond seasonality, other studies have deepened the short period effects of meteorological variables. They focus, in particular, on the effects of extreme temperature levels, both cold and heat waves, on survival. A summary of extreme temperature wave effects is reported in Ekamper et al. (2009), in which the authors claim that "The precise effects of extreme heat or cold depend not on temperature alone, but also on specific conditions in which the temperature decline or rise took place, and on other climatic conditions" (Ekamper et al., 2009, 389). Other studies on this topic in North-East Italy flag up the relationship between extreme cold during winter and neonatal mortality. Dalla-Zuanna and Rosina (2011), for instance, look at the correlation between neonatal mortality and the minimum temperature level of the death day in some parishes in the Paduan countryside, during the 1818–1867 period. They point out that "a decrease of 1 °C corresponds to a 5% increase in the daily risk of death during the first month of life" (Dalla-Zuanna and Rosina 2011, 49). Derosas (2009) finds a strong association between mortality and temperature levels lower than 5 °C Celsius during the birth month. Scalone and Samoggia (2018), meanwhile, observe that lower temperatures on the day of birth significantly increased the risk of neonatal death. Indeed, they observe a 9% reduction in neonatal mortality risk for a unit increase in temperature at birth.

Similar results have been pointed out in studies applying analogous methodologies to data from Sweden; one of them reveals an increase in perinatal mortality during low temperature periods in northern parishes during the period 1800–1895 (Schumann et al., 2019). This last study, in particular, shows that mortality affected mostly the Sami ethnic group, which had different forms of behavior and a different socioeconomic status with respect to the rest of the Swedish population. Another research contribution on some parishes of the Umea area in 1880–1950 confirms the same relationship between winter temperatures and neonatal mortality. The authors assess territorial heterogeneity in mortality levels: mortality rates are lower in urban areas than in the countryside (Karlsson et al., 2021).

Air and water pollution

The medical literature focuses on the correlation between environmental pollution and some newborn characteristics, and between pollution and increased death risk as well. High concentrations of air pollution were significantly related to a higher risk of low birth weight or preterm births (Guo et al., 2019; Lacasaña et al., 2005). Historically speaking, however, the lack of measures on the air and water quality and on the environmental pollution makes any assessment of the past more difficult. Despite these difficulties, some scholars have explored the relationship between air pollution and mortality. Beach and Hanlon (2018), for instance, evaluating coal use levels in England and Wales, inferred from local industrial structure, and industry-specific coal use intensity, show that in the decade 1851–1860, industrial coal use explains roughly one-third of the urban mortality penalty. The authors, in particular, find strong evidence of a relationship between coal use and infant mortality. However, aside from this study, quantitative analyses of the consequences of air pollution before the twentieth century are very few (e.g., Heblich et al., 2021).

Moreover, a wide literature has assessed the effects of water pollution. Some studies, for instance, starting from the classical work of John Snow (1855), refer to the role of polluted water in the spread of cholera (Fornasin et al., 2011). Other papers are devoted to show, after the cholera epidemics, the improvement in domestic water quality and the elimination of polluted water in all Western cities from the nineteenth to the twentieth century (Alsan & Goldin, 2019; Ferrie & Troesken, 2008; Harris & Helgertz, 2019; Jaadla & Puur, 2016; van Poppel & van der Heijden, 1997). These studies focus on the role of such improvements in infant mortality reduction, even if water and environmental quality plays an indirect role in survival during the first month of life. During breastfeeding, when infants do not consume water, the risk of death is indirectly connected to water pollution, e.g., the mother's hygiene. Changes in the sourcing of water played a crucial role in mortality reduction: the removal of surface water, the use of quality wells and deeper pumping wells, the construction of piped water and of purification systems, and the removal of polluted water from city centers. However, these changes became relevant in Italian cities only in the second half of the nineteenth century. Before these improvements, the main sources of water pollution were the residues from artisan work (tannery, dying, etc.), as well the human and animal sewage. The urban structure of European cities saw the progressive transfer of sources of pollutants (workshops etc.) to peripheral areas. But, in the nineteenth century, cities still had the urban planning criteria of the early modern period, with productive activities in the secondary sector placed within the city walls. Though pollutants were produced outside the most central parts of the city, they appeared within the walls (Sori, 2001).

Udine saw a similar shift. Still at the end of the eighteenth century, dyeworks were, for instance, to be found on the western edge of the city. Moreover, the city was not equipped with an effective system for the separation of drinking and "dirty" water. Furthermore, large areas were devoted to agricultural crops within the city walls and their fertilization was based on animal and human sewage produced in Udine. Dirty water produced by artisans could also pollute the domestic water supply (Breschi & Fornasin, 1999).

Housing

Very few studies address the issue of housing in pre-transitional populations. This is due, in part, to the lack of reliable data (Fornasin et al., 2016). In present-day populations, one of the best-investigated risk factors is indoor smoke from burning coal or wood. "Burning solid fuels indoors for cooking or heating, particularly in open fires or stoves with poor ventilation, generates high concentrations of air pollutants" (Desai et al., 2011, 165). Studies in developing countries reveal a relationship between household air pollution, caused by biomass fuel use, and low birthweight, stillbirths, and perinatal and neonatal death (Desai et al., 2004; Naz et al., 2016; Neogi et al., 2015; Nisha et al., 2018). Studies on Italy in the nineteenth century highlight the bad hygienic conditions of the houses in which most of the population lived, both in the countryside and in the cities (DIRSTAT, 1886; Prosperi, 2019). One of the issues pointed out in studies on the hygienic conditions of Italian municipalities of the time related to the low quality of cooking and heating systems, especially in farmhouses. Housing quality in Udine was similarly compromised. A comprehensive description of house conditions, dating back to the second half of the nineteenth century, but valid for our observational period too, reveals a grim state of affairs (Baldissera, 1877). There were few latrines, poor ventilation, crowding, and a lack of the most elementary hygiene rules.

Nutrition and socioeconomic status

Several studies focus on the question of how neonatal mortality is related to the malnutrition of the mother during pregnancy, as it leads to low birthweight (Scott & Duncan, 1999). However, the mothers' social and economic status also represents a structural factor (Hart, 1993). For this reason, there is a correlation between food prices and neonatal mortality, with social and economic status proving to be relevant too. This area of literature has considered the patterns of social and economic status in territorial contexts with low heterogeneity. In general terms, higher levels of neonatal mortality are correlated with the lower social classes. In Venice, where farmers were absent, in the period 1850–1869, the children of salaried workers faced the highest risk of death (Derosas, 2009). While in the countryside near Bologna, in the period 1820–1900, where almost all the population was made up of agricultural workers, the most at-risk newborns were the children of farm laborers and day workers (Scalone & Samoggia, 2018). Studies in Sweden revealed higher mortality among agricultural rather than among urban populations. In particular, Karlsson et al. (2021), considering a segmentation of the population based on employment type, pointed out how children of farmers and workers faced higher mortality levels than the children of their middle-class correspondents. However, an overall comparison among different social and economic classes has not yet been possible because of the lack of studies considering a wider set of occupation types. Relative to the association between mortality and mother's nutritional status, several studies focus on periods of famine. Some authors have suggested that populations where women were exposed to famine during the last trimester of pregnancy and immediately after

childbirth suffered the highest levels of neonatal mortality (Scott et al., 1995). However, results of different studies on the Dutch Hunger Winter of 1944/1945 differ on the relationship between the increase in neonatal mortality and food shortages. In Stein et al. (1995), the main cause is malnutrition, while in Hart (1993), a greater role is assigned to fuel shortages and unheated homes.

In our study, we do not focus on periods of crisis which do not reflect a "normal" situation. In studies not considering periods of extreme food shortages, the nutritional status of the mothers is proxied by cereal prices, under the assumption that higher prices corresponded to a caloric deficit, particularly among the poorest. In the studies focusing on Italy, wheat prices are adopted as a proxy for food availability, even if the periods under study do not always correspond with the time of childbirth. In the aforementioned study on Venice, for instance, the data on wheat price refers to the third quarter of gestation. Here, an increase in price leads to a significant reduction in mortality risks, even if the association between high staple food prices during late gestation and low temperature is particularly negative for the survival of day laborers' children (Derosas, 2009). Conversely, in the study, mentioned above, on the countryside around Bologna, the correlation between prices and survival is negative. However, in this study, the authors consider data on the prices of the year before childbirth as a proxy for food availability during pregnancy (Scalone & Samoggia, 2018).

Context and sources

Udine in the early nineteenth century

Udine is a small city in the North-East of Italy which, in the early nineteenth century, had around 13,000 inhabitants: there was a crude birth rate of about 36.4 per thousand and a crude death rate of 35.2 per thousand. It was the only urban center in Friuli, the region in the eastern part of the Napoleonic Kingdom of Italy and, until its fall in 1797, part of the *Stato di Terraferma* of the Republic of Venice. Despite its low population, Udine was, in socioeconomic terms, composite. Numerous artisan and commercial activities were to be found within its walls, which served a large rural hinterland. There were numerous mills along the two main canals that ran through the city and there were iron workshops and tanneries also. Textiles were important and there were many resident spinners and weavers. Udine was also an important administrative center. This period saw an increase in the central state bureaucracy and many white-collar workers migrated to Udine from other Italian territories. Within the city walls lived Friuli's most important families and landowners. But there were also modest farming families who cultivated land: these operations ranged from modest intra-mural market gardening to more extensive farming. Figure 1 shows the distribution of the population by socioeconomic status in the different city parishes: more specifically the father's occupation at the birth time.

The figure shows clusterings based upon social and economic status, even if a substantial overlapping of the different social categories in the same urban areas reflects
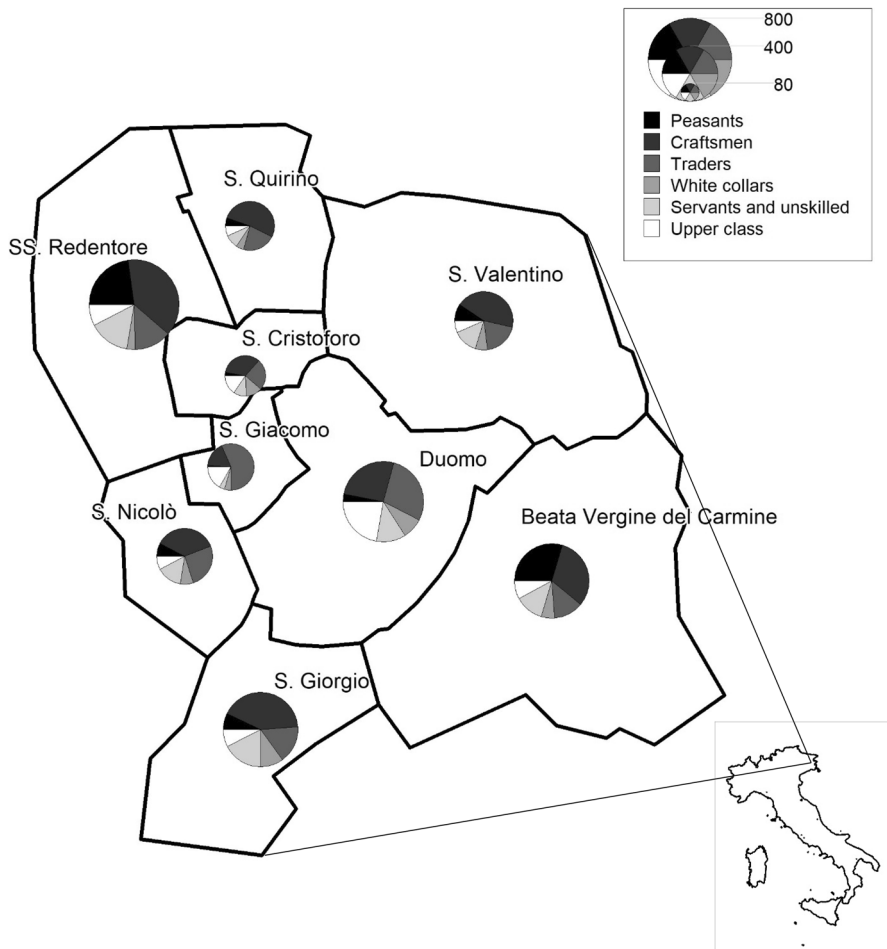
Fig. 1 Spatial distribution of occupations' categories (Udine 1807–1815). Source: Napoleonic civil registers. Registers of births

the small dimensions of the city. Udine can usefully be broken down into the three central parishes and six peripheral ones. In the urban parishes, occupations related to commerce, administration, and the higher social classes were more widespread, while in the outer parishes, especially the less densely populated ones, like the Redentore and Beata Vergine del Carmine parishes, there were more agricultural workers.

Given the particular focus, in our analysis, on housing and on the potential indirect connection between neonatal mortality and water quality, Fig. 2 shows the distribution of house numbers and the presence or absence of heating systems and the open-air canals into which the craftsmen's pollutants were released.

The 369 houses with heating systems are located in all areas of the city; however, in absolute terms, houses without heating are more numerous in the peripheral areas.
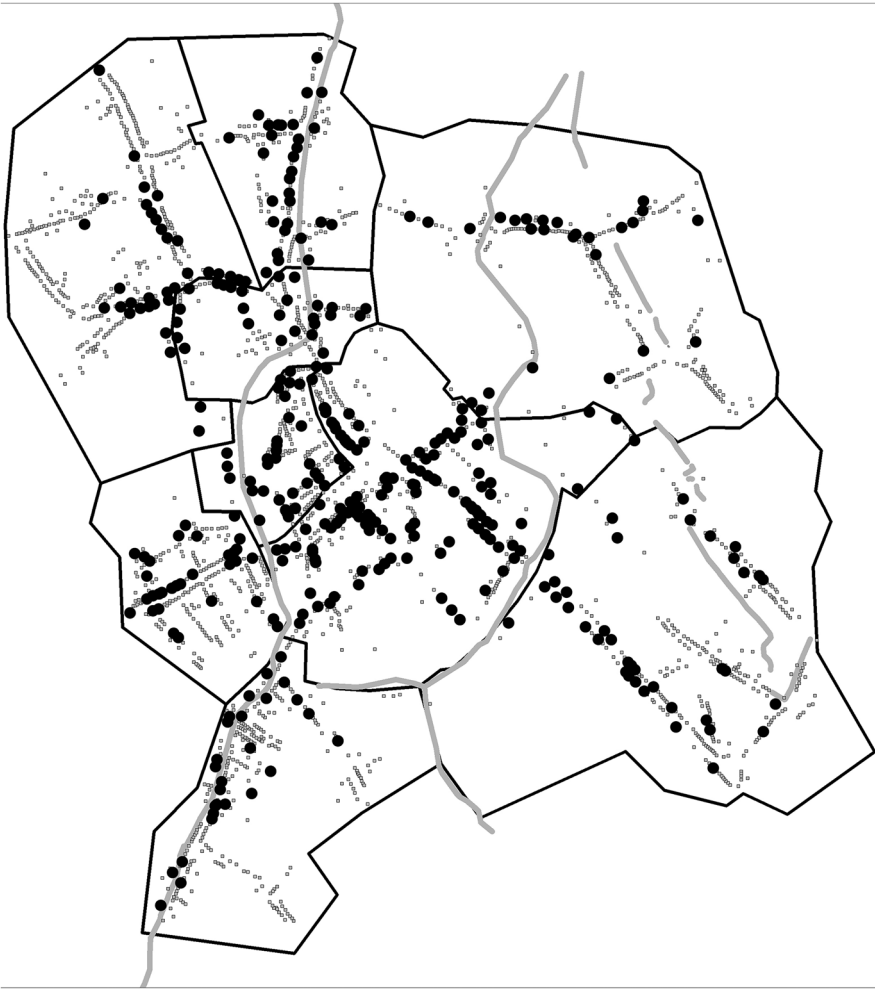
Fig. 2 Spatial distribution of canals and houses with and without heating system in Udine (1809). Source: House register 1809; Lavagnolo (1842–1850). Note: gray dots, houses without heating system; black dots, houses with heating system; gray lines, canals; black lines, parish borders

Demographic data: the Napoleonic civil registers

The availability and quality of data on Udine, so useful for chasing down the relationship between neonatal mortality and environment, are in some ways exceptional for the first two decades of the nineteenth century. The creation of the Kingdom of Italy in 1806 saw the introduction of the Napoleonic Civil Code across the country. This led to civil registers for births, deaths, and marriages. The present study uses the birth and death registers, which were kept from January 1, 1807, to December 31, 1815. These records report the name and surname of each newborn and deceased

citizen, and socioeconomic information, such as the occupation of the individual, parents, and spouse (in the case of deaths), and the date of the event too. Age at death is determined by merging birth and death data. Records report the house number which allows us to identify the house where events took place. Given the aims of our study, not all the available information has been taken into account. In fact, we consider only newborns whose place of birth and, especially, of death is identifiable in the urban territory. Thus, births and deaths outside the city walls are excluded due to the lack of detailed spatial and housing information.

We need also to stress that, as in all Italian cities at the time, Udine had a hospital where foundlings were left. The number of children abandoned in this period stands at 1477, or about a quarter of all births. These foundlings are excluded from the analysis because their peculiar characteristics would inevitably garble the results. In addition, the great majority of these children were not born in Udine. This is supported by the fact that these children were often left with baptism documentation including the parish where the child had been baptised. Most were from other, at times, quite distant locations. Of the 696 foundlings we have birthplace records for, only 28 were baptised in Udine itself. Of course, in addition to the lack of information on their parents, we do not know the exact birth location and, sometimes, we do not know where they died. Furthermore, their date of birth is unknown. This prevents us even from establishing the exact age at death. These infants cannot be compared, then, to legitimate children. They experienced a particularly harsh life and housing conditions, and, consequently, had a higher mortality rate. Given the exclusion of these abandoned children from our analysis, there is a relatively low number of deaths in the first 2 days of life and there is a lower death probability than that found in other studies (Derosas, 2009; Dalla-Zuanna & Rosina, 2011; Scalone & Samoggia, 2018). By considering legitimate children alone, whose age at death is known only for those who died within the city walls, we underestimate neonatal mortality. But, as a result, we can offer a more detailed analysis of the relationship between environmental conditions and mortality during the first month of life.

Houses and their location: the housing registers and the Lavagnolo city map

House numbering was introduced in many Italian cities at the turn of the nineteenth century. Udine had a first numeration in 1801 and another in 1809 (Mansutti, 1984). The 1809 register, the most detailed of the two (Breschi & Serio, 1999), lists a total of 2100 numbered houses. Some were uninhabited, others had more than one residence, and a few, even if identifiable, remained numberless (e.g., the towers on the wall had housing units). This source contains some demographic information on the families of owners and tenants and the number of fireplaces in each house, which is particularly important for our research. An unpublished "Livestock statistics" compiled in 1830, for the city of Udine, allows us to locate associated outhouses or stables in the urban territory. Despite this wealth of information, some gaps remain. The numeration system includes most of the city's buildings, but it excludes all non-private residences: e.g., prisons, barracks, monasteries, convents, and rectories.

Similarly, we cannot trace people with no fixed abode, or beggars, who congregated in cities.

These lists were not intended for the drafting of a city map: that was done only about 30 years later by the engineer Lavagnolo (1842–1850). But the total number of civic numbers and their position remained unchanged, which means that a given house can be pinpointed. The exact place of civic numbers allows the distribution of information across the different urban areas, like neighborhoods or parishes, which have been considered in the present study. Whenever there is a difference between the address of birth and of death (19 cases), we have considered only the death address.

Weather recordings: the data collection of Girolamo Venerio

Meteorological data sources for Udine in the period are particularly rich. This is due to the exceptional data collection carried out by the meteorologist Girolamo Venerio. Venerio collected data on atmospheric pressure, temperature, rainfall, and wind direction, at different hours of each day. He collected this information over more than 40 years, starting on January 1, 1802. This series stops the day Girolamo Venerio died, on March 4, 1843. His measurements are very accurate. Over the 40 years, he carried out daily checks on the functionality of the instruments and on their calibration, and he made also an effort to be consistent both in terms of the reading times and places. Every modification was documented by Venerio in order to evaluate and quantify the effects on the quality and comparability of the data (Cittadella, 2016, 214).

During the first two decades of the 1800s, weather data were collected three times each day (at dawn, at noon, and at sunset). The daily values considered in this study are calculated, as in the original observations, as the average of the minimum and maximum temperatures. Table 1 reports the average monthly temperatures during the period 1807–1815.

The temperatures measured by Venerio show the lowest values in the months of December, January, and February.

## Grain prices: the market of Udine

Udine had, since the Middle Ages, a grain market and it continued to be the region's main grain center, even after trade was liberalized in 1806. The collection of cereal and legume prices on the city market began in the sixteenth century. The quality of the series is excellent and it covers three centuries without interruptions. In fact, the dataset is so exceptional that it appears in one of the most important general works on European economic history (Braudel & Spooner, 1967). Prices were collected twice a week until the second Napoleonic occupation and once every 2 weeks in the period from 1807 to 1830, the period of our research.

Collection criteria changed several times over the centuries. But its aim remained that of providing the average grain price (Fornasin, 2000). In our study, we use corn rather than wheat prices, which may be an unusual decision. Even if these two series

Table 1 Monthly temperatures in Udine in degrees Celsius (1807–1815)

Month	Min	Mean	Max
Jan	−1.07	1.95	4.97
Feb	0.65	4.28	7.91
Mar	3.20	7.50	11.81
Apr	7.59	12.14	16.70
May	13.98	18.80	23.61
Jun	16.00	20.75	25.51
Jul	18.11	22.91	27.71
Aug	18.05	22.63	27.20
Sep	14.39	18.53	22.66
Oct	10.31	13.85	17.39
Nov	5.20	8.08	10.96
Dec	0.83	3.68	6.53

are correlated, we prefer to adopt corn prices because corn was the cereal typically bought by the poorest. Figure 3 reports the monthly wheat and corn prices from January 1785 until December 1825. Sudden rises in prices during the period covered by our research are absent. The highest price levels are recorded for 1815, when the upward trend resulting in the food crisis of 1817 began. This hit Friuli particularly hard.
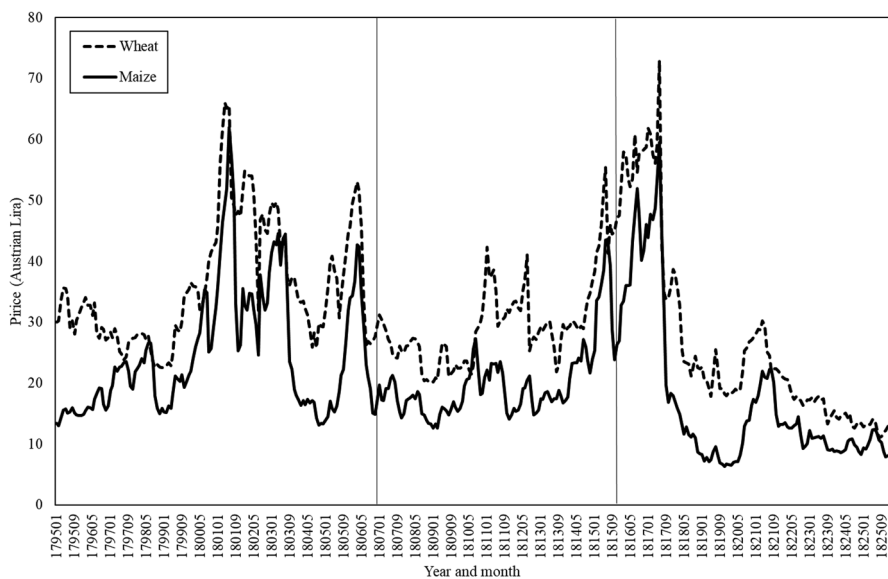
Fig. 3 Monthly prices of wheat and corn. Udine grain market 1795–1825. Note: all prices are converted in Austrian Lire/hectoliter

Methods

We firstly investigated the phenomenon of interest through some descriptive analyses on the distribution of neonatal mortality. Then, to assess the relationships between neonatal mortality and environmental factors, we adopted multivariate statistical tools. In line with other studies on this topic (Scalone & Samoggia, 2018), we took on an approach based on the derivation of two different datasets. The first is based on a record for each child born in Udine in the period from 1807 to 1815. It collects both information on the characteristics of each child and the data on environmental aspects that may affect death within the first month of life. In particular, some time-invariant variables like gender, multiple births, spatial location, socioeconomic status, and housing are included.

The second dataset, instead, has a long shape. It presents, for each child, as many records as the days of survival during the first month. In this dataset, the contextual variables, considered in the first dataset, are constant at the child's level. Several time-dependent variables are added, such as daily temperature, prices, and the infant's age. Moreover, only deaths during the three winter months (December, January, and February) are included. This selection was made on the basis of indications in the literature: during winter there are the lowest temperatures and the highest neonatal mortality levels (see Table 4).

In particular, a logistic regression model is estimated on the first dataset for the probability of death within the first month of life, while a discrete-time event history analysis is considered for the second dataset (Allison, 1982). This two-step approach is aimed at identifying the structural factors affecting neonatal mortality in Udine and checking their consistency with the main literature results and for deepening the role of assessed factors on newborn survival during the first month of life by means of a discrete-time event history model.

Of course, our methodological approach is limited by the data availability. In historical context analyses, it is generally difficult to get the information necessary for estimating the models adopted in our research. This study represents an exception since the time-dependent variable series employed offers quality and detail very similar to data collected in much more recent times.

In the first model, we consider the season of birth as, according to the literature, we expect a higher death risk during the winter months. Then, we consider the spatial distribution of neonatal deaths within the city, which represents a proxy for environmental quality. Udine had a relatively low level of territorial segregation (Fig. 1) and the different levels of neonatal mortality might depend more on environmental quality rather than on the different socioeconomic status of inhabitants. Here, we use the radial grid provided by the parishes. It is not, of course, possible to understand the environmental details at that time, but we can assume that the central area had better environmental conditions than the periphery. On the periphery, there were agricultural activities and the crafts with most pollutants.

As regards the houses, the variables considered are heated rooms and stables for cattle and horses. The presence of heated rooms is included to verify whether heating represents a risk factor for neonatal mortality. The presence of a stable, adjacent

to the house, may indicate, meanwhile, poor hygienic conditions even if, in some cases, livestock are used as an alternative heating source. Moreover, we use the occupation of the newborn's father as a proxy of socioeconomic status. It should be noted that the wide variety of occupational categories considered in this study are not easily found in the literature. Finally, demographic aspects such as gender and the distinction between single or twin births are considered control variables, and higher levels of mortality in males and twins are expected.

Furthermore, the model includes time-dependent variables such as corn prices, temperature, and age, which in the historical-demographic literature are generally correlated with neonatal mortality. To assess the role of prices and temperatures on neonatal mortality, we adopt an "experimental approach." Prices represent, from a historical point of view, a proxy for food intake. In the literature, their effect is not univocally assessed. To investigate the role of prices, several alternative models have been adopted in our study, including different observational periods, both during pregnancy and after birth. We have also tracked wheat and corn prices. Finally, we have chosen to adopt corn prices during the last 3 months of pregnancy. Most studies assess the positive effect of prices on neonatal mortality, but these kinds of results may be affected by years with exceptional price levels, which do not represent an issue in our period of study. With regard to the temperature effects, the little research conducted on this topic from a historical perspective does not offer a solid theoretical framework. Some scholars consider the temperature at birth (Scalone & Samoggia, 2018), others temperature in the month of birth (Derosas, 2009) or on the day of death (Dalla-Zuanna & Rosina, 2011). Our choice, based on the results of several estimated models, is to consider the average temperature of the last 2 days before death. A negative relationship between temperature and the probability of death is expected. The model, finally, takes into account the infant's age, measured day by day from birth to death or, for survivors, at the end of the first month of life. We expect a decreasing probability of death as the age (survival days) increases.

Table 2 Neonatal mortality in the parishes of Udine (1807–1815)

Parishes	Births	Deaths 0–29	Neonatal mortality
Duomo	676	50	74.0
S. Giacomo	260	24	92.3
S. Cristoforo	193	16	82.9
B.V. del Carmine	607	62	102.1
S. Giorgio	605	60	99.2
S. Nicolò	371	42	113.2
SS. Redentore	811	106	130.7
S. Quirino	292	37	126.7
S. Valentino	407	61	149.9
Total	4222	458	108.5

Table 3 Neonatal mortality by fathers' occupations (Udine 1807–1815)

Fathers' occupation	Births	Deaths 0–29	Neonatal mortality
Peasant	517	47	90.9
Craftsman	1514	179	118.2
Merchant	904	88	97.3
White collar	281	29	103.2
Servant and unskilled	545	60	110.1
Upper class	461	55	119.3
Total	4222	458	108.5

Results of descriptive analysis and models

The neonatal mortality rate in the early nineteenth century in Udine was 108.5 deaths per 1000 live births. This value, as argued in the "Context and sources" section, represents a slight underestimate. However, we can evaluate, in Table 2, how neonatal mortality was distributed throughout the city.

The table shows that neonatal mortality varied somewhat from one parish to another and, as expected, it reaches its lowest levels in the central parishes of the city, where environmental quality was better. Table 3, on the other hand, shows the data on neonatal mortality with reference to the father's occupation. Occupations are grouped into six categories following only partially HISCLASS (Van Leuwen & Maas, 2011). This hybrid choice allows us to identify categories with an adequate number of cases in relation to the social class of their members.

From the table, there is the unexpected result that upper-class children faced the highest risk of dying in the first month of life. The children of peasants, on the other hand, show the lowest risk. Table 4 presents the neonatal mortality values by season.

The table highlights excess winter mortality in neonatal age in Udine, which affects all occupational categories.

Although descriptive analysis suggests, clearly, some relationship between environmental factors and neonatal mortality, we decided to delve deeper into this evidence by means of multivariate statistical analyses. Based on the previous results, two separate models have been estimated, a logistic regression model, for the assessment of factors affecting neonatal mortality, and a discrete-time event history model for evaluating day-by-day neonatal survival during the winter season. Tables of results report the percentage of observations for all variables, the odds ratios, and

Table 4 Seasonality of neonatal mortality (Udine 1807–1815)

Season	Births	Deaths 0–29	Neonatal mortality
Summer	982	68	69.25
Autumn	1047	80	76.41
Winter	1139	193	169.45
Spring	1054	117	111.01
Total	4222	458	108.48

their significance levels: our results are based, note, on the adoption of a 0.10 cutoff. The estimation results of the logistic model are reported in Table 5.

The results reported in Table 5 show, in line with those of Table 4, that neonatal mortality in the city of Udine was higher during the winter months, even if the spring months result proved to be dangerous for newborns, too. These aspects have been pointed out in other studies on the Veneto Region (Derosas, 2009; Dalla-Zuanna & Rosina, 2011). As expected, the outer parishes have a higher risk of death. The indicator variable for the presence of heated rooms and stables proves to be not significant. The estimated effect of family socioeconomic status confirms the results

Table 5 Logistic regression model results. Risk factors of neonatal mortality: Udine 1807–1815

	%	Odds ratio	$P > z$
Sex (ref. M)	53.1		
F	46.9	0.844	0.098
Multiple births (ref. single)	98.1		
Twins	1.9	8.729	0.000
Season of birth (ref. summer)	23.3		
Autumn	24.8	1.220	0.255
Winter	27.0	2.935	0.000
Spring	25.0	1.751	0.001
Parish (ref. Duomo)	16.0		
S. Giacomo	6.2	1.356	0.254
S. Cristoforo	4.6	1.241	0.481
B.V. del Carmine	14.4	1.656	0.018
S. Giorgio	14.3	1.431	0.091
S. Nicolò	8.8	1.886	0.005
SS. Redentore	19.2	2.347	0.000
S. Quirino	6.9	2.030	0.003
S. Valentino	9.6	2.416	0.000
Heating system (ref. no)	80.0		
Yes	20.0	1.203	0.165
Stable (ref. no)	88.0		
Yes	12.0	0.873	0.435
Fathers' occupation (ref. peasant)	12.2		
Craftsman	35.9	1.492	0.034
Merchant	21.4	1.272	0.253
White collar	6.7	1.378	0.230
Servant and unskilled	12.9	1.322	0.204
Upper class	10.9	1.653	0.030
Constant		0.029	0.000
Number of obs		4222	
LR chi2(20)		174.30	
Prob > chi2		0.000	
Pseudo R^2		0.060	
Log likelihood		−1362	

of the descriptive analysis. Compared to the reference category (peasant), all other categories show a higher death risk, even if this is not always statistically significant. The highest death risk is for the artisan category and the upper class. Finally, we observe, as expected, a higher level of mortality among males and twins.

Table 6 Discrete-time event history analysis. The factors affecting neonatal mortality. Udine (1807–1815)

	%/mean	Odds ratio	$P>z$
Sex (ref. M)	48.0		
F	52.0	0.770	0.077
Multiple births (ref. single)	98.3		
Twins	1.7	5.936	0.000
Parish (ref. Duomo)	17.5		
S. Giacomo	6.8	0.868	0.748
S. Cristoforo	4.4	0.869	0.798
B.V. del Carmine	14.4	2.548	0.002
S. Giorgio	14.8	1.515	0.182
S. Nicolò	8.4	1.995	0.045
SS. Redentore	17.0	2.909	0.000
S. Quirino	7.1	2.732	0.002
S. Valentino	9.6	3.061	0.000
Heating system (ref. no)	79.2		
Yes	20.8	1.473	0.032
Stable (ref. no)	87.3		
Yes	12.7	0.668	0.145
Fathers' occupation (ref. peasant)	13.9		
Craftsman	34.7	2.384	0.005
Merchant	21.5	2.410	0.008
White collar	6.1	2.420	0.032
Servant and unskilled	13.4	2.176	0.028
Upper class	10.4	3.166	0.001
Corn price (last 3 months of pregnancy)	8.9	0.903	0.032
Average temperature C° (2 days before)	3.6	0.964	0.079
Age in days (ref. 0–1)	7.5		
2–3	7.4	2.745	0.002
4–6	10.7	1.892	0.053
7–13	23.7	1.596	0.128
14+	50.8	0.665	0.191
Constant		0.003	0.000
Number of obs		30,421	
LR chi2(23)		136.01	
Prob > chi2		0.000	
Pseudo R^2		0.058	
Log likelihood		−1101	

Table 6 reports the estimation results of the discrete-time event history model. This model focuses solely on the meteorological winter season. We have estimated this model on an "extended winter" period, with some spring months added in. Its results confirm the factors' effects assessed in the December-January–February model and are not reported here for the sake of brevity.

The table confirms the covariates' effects on neonatal mortality in peripheral parishes pointed out in the logistic regression. The discrete-time event history analysis suggests a significant effect for heated rooms in reducing survival, while the effect of stables is not statistically significant. We have estimated this model including the interaction terms between heating and social class categories, which, however, do not show statistically significant effects. This outcome confirms the hypothesis that heating itself proves a risk factor for mortality. Moreover, all social classes and the upper class, in particular, have higher death risks, compared with the reference category of peasants. Regarding time-dependent factors, an increase in corn price leads, unexpectedly, to a reduction in neonatal mortality, while, as expected, an increase in temperature means better chances of survival in the first month of life. Gender and multiple births confirm the effects already pointed out in the first model. As regards the age effect, in the first week of life, death risk is significantly higher during the days 2–3 and 4–6, compared to the reference class (days 0–1). The age role relative to subsequent days is not significant. This pattern of the age effects on mortality has been observed in other studies for northeastern Italy (Dalla-Zuanna & Rosina, 2011).

Discussion and conclusions

Analyses on neonatal mortality in Udine in the very early nineteenth century confirm several aspects pointed out in other studies of northeastern Italy in the same period. In particular, there is a significant relationship between weather temperature and deaths. More specifically, the temperature level near the death date is crucial. We can assess how the low temperature levels affect mortality after birth. This represents an external risk factor, not correlated with pregnancy, and it might explain the higher frequency of deaths after the first 2 days of life but within the first week.

Beyond these unsurprising results, anticipated by other studies, our analysis allows us to deepen other aspects such as the mortality spatial distribution. There was higher mortality in the peripheral parishes. This distribution could be correlated with social make up and worse environmental conditions. Thus, higher neonatal mortality might be an indirect effect of craftsmen's pollutants.

A relevant result of our study is that the presence of a heating system in the house increased the probability of death. This result is relevant if we consider neonatal mortality during the winter only, when heating systems were used. This evidence seems in contrast with the understood highlighted effect of low temperature levels on neonatal mortality. Substantially the presence of heating does not seem to have the effect of protecting the baby, rather there is the negative effect from higher indoor pollution. This suggests that heated rooms represented a risk factor for mortality because of solid fuel combustion. Our results for Udine, in the early nineteenth

century, are similar, in this respect, to those found in the literature for developing countries, where a significant correlation between neonatal mortality and indoor pollution from heating has been assessed. To the best of our knowledge, this historical association represents a novelty in the literature and offers a better understanding of the mechanisms that connect cold temperatures, solid fuel combustion, and neonatal mortality. Our results might prove useful in encouraging policies to protect neonates in developing countries or in deprived areas.

The positive role of stables associated with houses is not statistically significant. But this aspect would deserve a more careful study. Even in the second half of the nineteenth century, during winter, peasants spent part of their time in the barn, because it was a warmer environment thanks to the cattle presence (Panizza, 1890). For this reason, the stable offered protection to the newborns in the first weeks of life from cold winter temperatures, while, during summer, it became, instead, a risk factor because of summer diarrhea (Morgan, 2002), which may affect infants after weaning only.

The most surprising result regards the relationship between neonatal mortality and social classes. In the literature, the higher survival rate among upper-class children has been a matter of study. However, studies tend to take into account a lesser range of social and economic classes or focus on rural contexts, or on a few parishes with a relatively limited number of upper-class families (e.g., Derosas on Venice). As described in the "Context and sources" section, we do not take into consideration foundlings as it proves impossible to identify the parents. To a large extent, however, we can assume that the parents or, at least the mother, belonged to the servant and unskilled workers category. Their neonatal mortality levels should be reasonably higher than reported. Despite this, it is surprising to observe the lowest neonatal mortality among peasants, and the highest among the upper class. This unexpected result might be an effect of breastfeeding practices. Breastfeeding has long been recognized as a guard against infant mortality and was generally adopted in rural contexts, among peasant families. It was rarely adopted in the upper classes: upper-class families typically brought in wet nurses. However, the use of wet nurses caused a delay in breastfeeding and this may represent a further risk factor for neonatal death (McLaren, 1978; Matthews & Grieco, 1991). Furthermore, we support the idea that the higher probability of survival among peasants' infants could be correlated with the absence of heated rooms in their houses. Peasant infants were generally born in stables that represented a heated but not polluted environment. Thus, even if the hygienic conditions in the stable were poor, living inside or nearby during the cold months was less dangerous as this heat source was healthier than heat from solid fuels burned inside. All these evaluations allow us to offer an interpretation of higher mortality in peripheral parishes, where, in line with the results provided by our models, there was an excess of mortality among children from non-agricultural families. In these parishes, there was a high percentage of salaried workers and artisans who had poor living conditions and who were in contact with many artisan pollutant sources. Thus, these families did not have either heated rooms or stables.

The last aspect to disentangle is the price-of-corn effect. Unexpectedly, an increase in prices during the last 3 months of pregnancy leads to a decrease in mortality levels. Model results are, however, consistent with the idea that an increase in

prices affects general conditions during pregnancy. This causes, for instance, fetal mortality, but does not affect the survival of children. During the last period of pregnancy, fetal growth is accelerated, which results in greater consumption of the fat deposit in mothers (Rush, 2001), and poorly fed women can thus affect the health of the fetus they are carrying. Corn prices are directly related to survival if both the last period of pregnancy and the previous months are included in the analysis. The association between mortality and food prices is relevant in the last 3 months of gestation, and maybe before as well.

Declarations

Conflict of interest The authors declare no competing interests.

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