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A Cliometric Reappraisal of the Impacts of Plague Outbreaks on Pre-Industrial France

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Abstract. This paper examines the impact of plague outbreaks on nominal wages, real wages, and prices in pre-industrial France. We employ a cliometric approach, relying on a database spanning multiple centuries, drawn from Ridolfi (2019). To analyze the impact of plague outbreaks, we apply an outlier detection methodology to detect atypical points that influence the evolution of our time series. We tackle the following question: over the period 1280–1789, did plague significantly influence the evolution of real wages, nominal wages, and prices, and, if so, what was the nature of this impact? We find that plague outbreaks had differentiated impacts across variables, occupations, and periods. Real and nominal wages responded differently depending on contextual factors, while prices were influenced by both plagues and famines.
Keywords: Cliometrics, Epidemics, Outliers, Plague, Prices, Wages
JEL classifications: C32. E32. N33.

1 Introduction

The coronavirus pandemic has shed light on the impact of infectious diseases on human societies. However, COVID-19 was far from being the first infectious disease in human history to have a global impact. Over the past thousand years, multiple pathogens have caused pandemics, including *Yersinia pestis* (the plague bacterium), *Vibrio cholerae* (the cholera bacterium), influenza viruses, and most recently, the coronavirus *SARS-CoV-2*. Yet the global impact of pandemics has been underestimated in recent scientific work and therefore needs to be re-examined. Indeed, as Huremović (2019) argues, pandemics have profoundly shaped our societies, resulting in deep economic and demographic changes. To better understand what follows, a distinction between epidemiological terms is in order. According to Grennan (2019) (p. 910), "the terms endemic, outbreak, epidemic and pandemic relate to the occurrence of a health condition compared to its predicted rate as well as to its spread in geographic areas"; "an endemic condition occurs at a predictable rate among a population. An outbreak corresponds to an unpredicted increase in the number of people presenting a health condition or in the occurrence of cases in a new area. An epidemic is an outbreak that spreads to larger geographic areas. A pandemic is an epidemic that spreads globally." Based on this, we use the term "pandemic" here to describe mass global infectious diseases and "epidemic" for more local infectious disease outbreaks.
Pandemics have occurred throughout human history; some of the worst ones, like the Antonine Plague and the Justinian Plague, date back over 2000 years.[1] These two pandemics were the first

[1]The Antonine Plague was probably caused by smallpox (Alfani, 2024).

to be well-documented by physicians, such as Galen (Huremović, 2019). This paper, however, examines a database that spans the period 1280–1789, which means the focus is on medieval and early-modern plague outbreaks such as the Black Death and other local plague episodes of the 17th and 18th centuries.

These pandemics and epidemics were major drivers of social and economic changes. According to Barbara (2021), there are several channels of transmission of epidemics into the economy. They impact the supply side through the labor force, working hours, and productivity, and also impact demand through consumption and investment. This paper focuses on understanding the economic changes that can be attributed to plague pandemics and epidemics between the Middle Ages and the early modern period. It also examines how these outbreaks relate to other events, such as wars and famines.

Recent literature on the matter suggests the importance of reevaluating the role of infectious diseases in history (Alfani and Murphy, 2017). Indeed, as highlighted by Pamuk (2007) (see also Allen, 2001; Clark, 2007; Voigtländer and Voth, 2013; etc.), multiple structural changes key to industrial development could find their roots in the pandemics of the Middle Ages and the Black Death period. To understand how and to what extent plague outbreaks have influenced human history, the Black Death serves as a pivotal example It not only prompted a temporary ceasefire during the Hundred Years' War but also profoundly disrupted the social order through riots and the emergence of movements such as the flagellants and the Jacquerie in France, and reshaped labor markets (Jedwab, Johnson, and Koyama, 2022; Pamuk, 2007). These historical changes were directly generated by the Black Death, since troops needed to recover from the epidemic that was decimating their ranks, and workers had seen their conditions worsen. During this period, the Black Death was responsible for the death of at least 30% of the population, a demographic shock that led to numerous economic changes. Another strand of the literature argues that the Black Death may have facilitated economic and political power growth of a specific subregion of Europe through the phenomenon known as the Little Divergence (Pamuk, 2007; Prados de la Escosura and Rodríguez-Caballero, 2022).

While our database contains data from multiple plague outbreaks, this does not include the Spanish flu or the 2019 coronavirus outbreak, as they are recent and more modern diseases. However, it was during the COVID-19 pandemic that the question of the economic impact of infectious diseases was raised most urgently (Atkeson, 2020; Eichenbaum, Rebelo, and Trabandt, 2021; etc.).

Our paper is in line with the work of Prados de la Escosura and Rodríguez-Caballero (2022) and other papers that discuss the lasting effects of plague and other macroeconomic events in the context of the debate on the sources of the Little Divergence and the long-term evolution of macroeconomic variables (Alfani and Percoco, 2019; Pamuk, 2007; Voigtländer and Voth, 2013; etc.). To recontextualize, the Little Divergence refers to the differential evolution in economic characteristics between various countries of Europe during the early modern period, which in some countries facilitated the first Industrial Revolution. We will investigate only a part of this phenomenon, since we are working only with French data.

More specifically, this paper considers the impact of plague pandemics and epidemics on nominal wages, real wages, and prices throughout pre-industrial France, and in particular whether these effects are lasting. We also conduct an analysis in order to measure how outbreaks of plague interplay with other major shocks of the period (famines, wars, etc.). To investigate these questions, we used a database on wages (nominal and real) and prices in France for the period from 1280 to 1789, coming from Ridolfi (2019). We make two main contributions to the literature. First, to our knowledge, this paper is the only one to tackle the history of plague outbreaks and their impact on various economic variables during this period in France. We provide a deep assessment of the effects of plague on the pre-industrial economy of France in terms of magnitude, sign, and persistence, using an outlier detection analysis. Second, this paper extends its analysis to other types of shocks, namely wars and famines, allowing for a comparison and an

interplay analysis between these different shocks and previously identified outbreaks of infectious diseases. This also permits a better understanding of the link between these shocks. To answer our research question, we rely on a cliometrics approach: the outlier methodology. With this technique, we evaluate the impact of various out-of-range observations on our variables. More specifically, the outlier methodology allows us to develop a counterfactual analysis through an $ARIMA$ model by detecting and eliminating significant outliers to evaluate their impact. This approach is very suitable for pandemic and large-scale epidemic analysis, as these are exceptional historical events: in a word, outliers.
The paper is divided into six sections. First, we discuss plague history in pre-industrial France. Second, we shed light on the links between plague and our variables. Third, we present our database and describe our main variables. Fourth, we implement the outlier method on our data. Fifth, we explain the results. We conclude with final remarks.

2 Plagues in pre-industrial France

Plague is an infectious disease caused by the bacterium *Yersinia pestis*. It manifests as fever, weakness, headaches, and other symptoms. Its incubation period is known to last between one and seven days. There are three types of plague; each one affects a different part of the body and causes different symptoms. The first is pneumonic plague, which infects the lungs, causing respiratory problems; the second is bubonic plague, which affects the lymph nodes, making them swell; and the third is septicemic plague, which enters the bloodstream and can cause tissue necrosis and discoloration (Zietz and Dunkelberg, 2004).
In this paper, the first plague pandemic of interest, a bubonic one, is the Black Death. It emerged in East Asia around 1334, spread across Central Asia, and arrived in Europe in 1347 through land and trade routes (Huremović, 2019).[2] Plague outbreaks are estimated to have caused approximately 200 million deaths in Europe by the early 19th century, occurring in multiple waves over several centuries (Piret and Boivin, 2021). The most devastating of these was the Black Death, which alone is believed to have caused around 25 million deaths between 1347 and 1351, with cumulative fatalities surpassing 150 million by 1400 (Huremović, 2019). This pandemic led to the death of at least 30% of the European population and triggered a succession of recurring outbreaks. We focus on this pandemic due to its scale and social impact. It affected the social order in many ways. The flagellant movement appeared in the decade following the Black Death, while, in 1358, northern France was shaken by the *Jacquerie*, a major peasant and bourgeois revolt (Cohn, 2007; Jedwab, Johnson, and Koyama, 2022). It even impacted the composition of society: Alfani (2021), for instance, observed a narrowing of inequalities in Toulouse, where the Gini index of income inequality declined from 0.752 in 1335 to 0.606 in 1398. The governmental response to the Black Death was initially religious (Huremović, 2019). Scientific authorities, at a loss, blamed the pandemic on the alignment of three planets (Horrox, 1994). The medical response was weak, with a prevailing belief in the inhalation of aromatic vapors and other magical protections (Hajar, 2012). However, the plague was later recognized by the authorities as contagious, and control measures were sometimes implemented to check the spread of the disease, including quarantine, the disposal of victims' bodies and possessions, sanitary cordons, separation between healthy and infected people, and mandatory isolation measures (Mackowiak and Sehdev, 2002). The first known quarantine took

[2]The first bubonic plague pandemic was the "Justinian Plague", which originated in North Africa (Ethiopia or Egypt) and spread across the Eastern Roman Empire and nearby countries (Little, 2007). Although bubonic diseases were reported before the Justinian Plague, this is the first undoubted outbreak of plague (Zietz and Dunkelberg, 2004). It occurred between 541 and 543 and killed around 100 million people across the Roman Empire (Piret and Boivin, 2021). It appears that this pandemic struck in waves, following a cyclical pattern of 8 to 12 years for two centuries before it eventually disappeared.

place in Ragusa in 1377, where all new arrivals had to spend 30 days on a nearby island called Lokrum (Mackowiak and Sehdev, 2002). However, the critical role of rats was overlooked and was not discovered until the 19th century (McEvedy, 1988). Due to this lack of information on the disease's mode of transmission, it proved difficult to contain. Plague doctors emerged during that time, tasked with assisting people and recording deaths.
Another high-activity period of plague began during the 17th century. It probably broke out in northern France in 1623 and spread to England, France, Germany, the Low Countries, Switzerland, and Italy. In parts of France and Italy, these plague outbreaks are usually considered the worst after the Black Death. France was hit by multiple waves of plague in 1603, 1628, 1652, and 1668 (Alfani, 2013). To underline the severity of this high-activity period, Alfani (2013) showed that in the city of Lyon alone, between 1628 and 1629, the disease killed about 35,000 people. On a more global scale, it killed around 2.2 million in France (11–14% of the population) and at least 8 million in Europe (Alfani, 2013). In the same vein, the Marseille plague of 1720–1722 was one of the most important epidemics of the 18th century in France, with 100,000 deaths in the southern region of France (Signoli, 2022; Slack, 2022). This plague came from the sea and was thus a consequence of international trade. The boat *Grand Saint Antoine* brought the plague back to France by entering the port without respecting the sanitary requirements. After its arrival on the 20th of June 1720, a woman fell sick marking the first case of many more (Devaux, 2013). Compared to the Black Death period, however, plague episodes of the 17th and early 18th centuries were handled more effectively, as governing authorities had learned from earlier times (Alfani, 2022).
When discussing the plague in France, Biraben (1975) showed that the country was practically continuously hit by plagues between 1347 and 1670. It should also be noted that the plague is a re-emerging infectious disease. Between 2010 and 2015, 3,248 plague cases were recorded worldwide; however, there is now a vaccine for the disease.

3 Plague and macroeconomic variables

3.1 Wages and plague

The main objective of our paper is to analyze the impact of plague pandemics and epidemics on wages (nominal and real). According to Malthus, pandemics play a regulatory role; just like wars, pandemics are necessary to avoid overpopulation (Mtiraoui, 2020). A reduced population due to the spread of an infectious disease can raise wages through labor scarcity (Clark, 1998; Voigtländer and Voth, 2013). This is valid unless the decline in labor supply is matched by a proportional drop in labor demand (Alfani and Percoco, 2019). The literature leans toward the view that pandemics drive real wage growth upward. For example, the Black Death had a very high death rate and decreased the labor supply by about 25% to 40%, leading to a real wage increase of 100% (Clark, 2007; Pamuk, 2007; Robbins, 1928). Clark (1998) simulated that, depending on the degree of factor substitution in medieval agriculture, the Black Death could have led to an increase in real wages ranging from 0% to 86%. However, the actual observed increase in real agricultural wages was approximately 64% by the mid-fifteenth century. Notably, the impact on real wages seems to be delayed by one generation: the Black Death's effect on real wages was not visible before the 1370s. This sluggishness can be due to workers' status and institutional rigidity (Clark, 1998). The author noted that the effect of population dynamics on real wages and land rents depended on how easily land and capital could substitute for labor in the production process. This means that the Black Death would have more impact on real wages if workers were not substitutable for capital. Furthermore, Humphries and Weisdorf (2015) challenged the idea of a uniform wage increase for all workers during and

after the Black Death. The authors emphasize that servant women did not experience a wage increase similar to that of men, implying that the "golden age" of wages post-Black Death did not extend to all women. In other words, different types of workers benefited differently from the Black Death's effect on wages, and this effect was not uniform across the laboring class.
Nonetheless, the increase in average real wages during this period could be seen as a source of the Little Divergence, as certain countries like England and the Low Countries managed to withstand the decline in real wages in the latter part of the Malthusian cycle (Clark, 1998; Pamuk, 2007). This is connected with questions surrounding the duration of the effect of the Black Death on wages, a question that is still under debate and is a subject of discussion in the present paper (see also Voigtländer and Voth, 2013; Ridolfi, 2019).
Overall, the Black Death led to an increase in real wages, but this statement needs to be tempered by the effect of state intervention. Indeed, variation in wages could have been constrained by structural and institutional events. Heckscher (1955) (p. 198) wrote that in France, "the effects of the Black Death provided a powerful motive for the first interference on the part of the state. The great pestilence had led to a rise in prices and particularly in wages, and the king took this as a motive for making the local bodies in Paris, above all the guilds, dependent on the royal institutions". Heckscher (1955) (p. 141) explained that this increasing regulatory oversight made labor markets freer: "The decree tended to make it easier for strangers to practice their crafts within the town; it even stipulated that any person who was able to practice a craft or introduce a commodity might do so and allow others to do the same". This kind of example shows that even during pandemics, institutions can put downward pressure on prices and wages. Another example that can be cited concerns the taxation (called *la taille*) levied on peasants during the Black Death period. The collection of this tax began to finance the Hundred Years' War against England, and this is also the period to which historians date the definitive birth of state finance in France (Jedwab, Johnson, and Koyama, 2022; Henneman, 1968). The types of taxation were various and appeared to be one of the many forces used to apply pressure on the labor market. Labor statutes also played an important role during the Black Death period, as institutional responses strengthen and significantly affected wages. During the 1350s in France, the government limited nominal wage growth with a laborers' statute of 1351 regulating wages, prices, and guild admittance (Jedwab, Johnson, and Koyama, 2022).
Later, in the seventeenth century, the 1628–1630 plague had no positive impact on real wages, even in Southern Europe, where epidemic mortality was as high as during the Black Death (Alfani, 2022). This change could be attributed to a better understanding of pandemic management by the authorities (Alfani, 2022). Different times, different results.
In this section, it has been reported that wages during pandemic episodes are sluggish and adjustments imperfect due to institutional and structural constraints. In sum, whether wages increase during plague outbreaks seems to depend on the historical period, institutions, and disease characteristics.

3.2 Prices and plague

Finally, we analyze the potential effect of plague outbreaks on prices. The literature on prices during the Middle Ages and the pre-industrial period is broad and complex, particularly in the context of plague. To identify different effects, we also refer to a broader body of work.
Edo and Melitz (2023) extensively discuss the impact of the Black Death on prices through changes in wealth and demand in England. Overall, the authors highlight that prices experienced an initial general increase after the Black Death, followed by a decline a few years later. According to them, these effects are directly linked to changes in wealth and adjustments in tastes. The initial inflationary effect is supported by the literature; however, the duration of

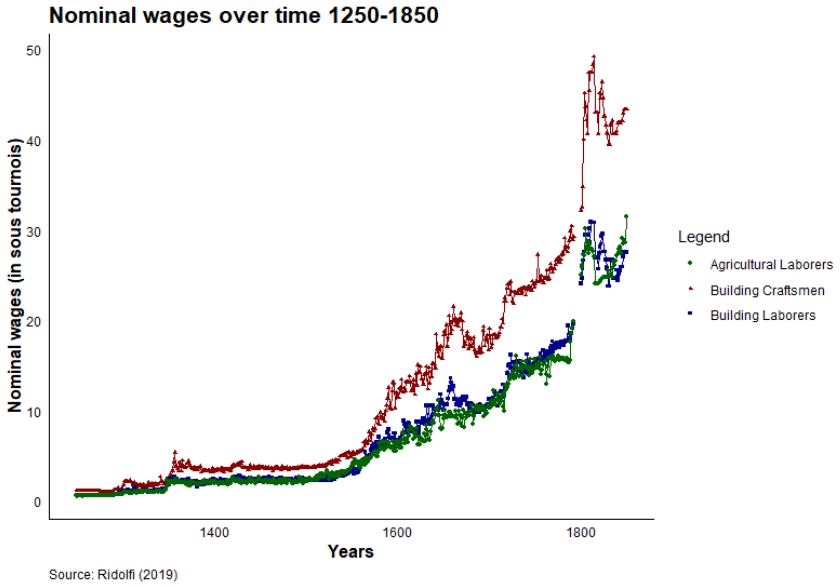
the inflation and the onset of the subsequent deflationary period are debated (Bridbury, 1973; Munro, 2004).
Nonetheless, while there is consensus on the inflationary period of the 1350s, the factors driving these changes remain a topic of discussion (Edo and Melitz, 2023). More broadly, the impact of pandemics on prices is still not fully understood, and this uncertainty is not limited to the context of the Black Death or plague. On the one hand, a smaller population reduces demand and may have a negative impact on prices. On the other, it also reduces the workforce and may have a positive impact on real wages in rural areas, leading to rising prices, especially for grain (Routt, 2008). The impact also depends on the nature of the goods. While increased demand for health products may lead to higher prices in the short term, the downturn in global demand may lead to price decreases (Jaravel and O'Connell, 2020). Also, the increase in overall wealth during the Black Death could have shifted demand toward luxury goods in England, most of which were imported, contributing to different price variations (Edo and Melitz, 2023). In the same vein, Malanima (2012) showed that wheat prices continued to rise for several decades after the Black Death. The authors attributed this to an increase in money per capita, arguing that the Black Death, while reducing output, did not destroy capital or monetary stock. Drawing from the Fisher equation, Malanima (2012) explained that a sudden drop in output (Q), with money supply (M) and velocity of circulation (V) unchanged, would lead to a temporary rise in prices. Furthermore, because wheat and agricultural products represented most of the consumption, the increase in agricultural prices strongly impacted the consumer price index. This phenomenon is not limited to the aftermath of the Black Death and could be expected following other major epidemics as well.
Thus, whether epidemics have a deflationary or inflationary impact depends on the relative strength of the transmission channels and the degree of institutional control over production costs (Baqaee and Farhi, 2022). Indeed, in the Middle Ages, the state tried to manage fluctuations in wages, which, in turn, had indirect consequences on prices (Cohn, 2007; Fisher, 1965; Penn and Dyer, 1990). Later on, and in another context with the Spanish flu, inflation seems to have appeared: Barro, Ursúa, and Weng (2020) linked the higher death rate with the higher inflation rate during that period. A distinction can be made between modern and pre-modern times: wage and price sluggishness appear to have characterized earlier pandemics such as the Black Death.

4 Database and limitations

4.1 Database

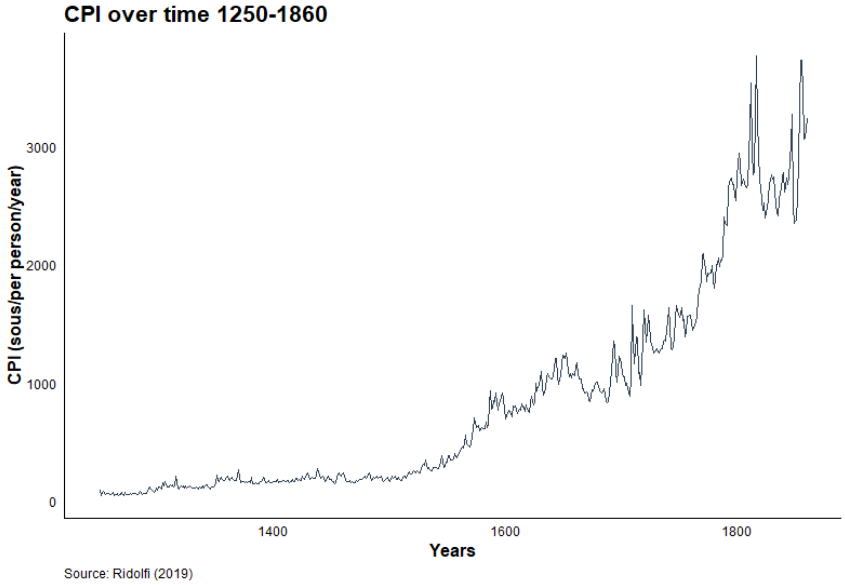
Our database covers the period from 1250 to 1860 and three main variables: nominal and real wages for various workers, and prices for France (expressed in sous tournois). The series comes from Ridolfi (2019). Our data series begins in 1250 and ends in 1860. Ridolfi's data are used for the pre-industrial period between 1280 and 1789.

Figure 1: Nominal wages in France, 1250-1850 (in sous tournois)



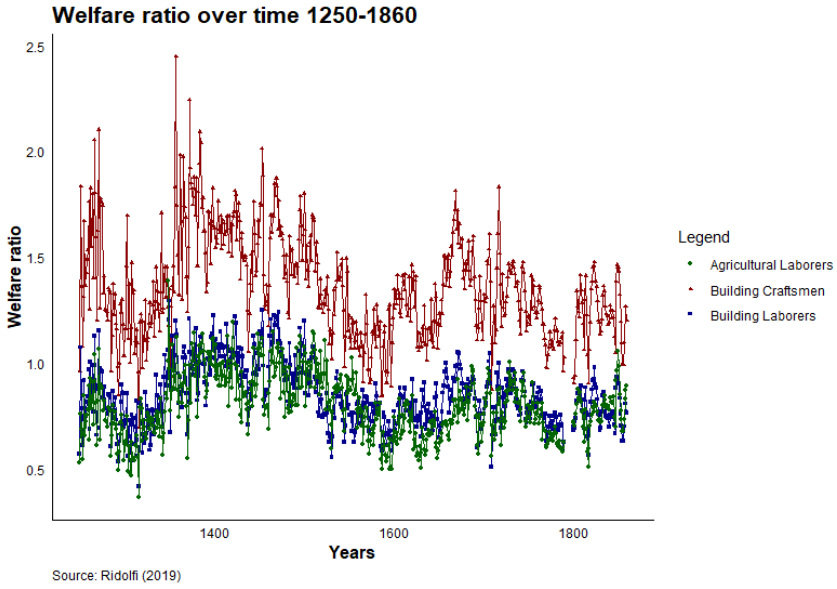
The series on nominal wages uses the more recent data provided by Ridolfi (2019) on the daily nominal wages of building laborers, craftsmen, and farm laborers from 1250 to 1850 (Figure 1), all expressed in sous tournois. To construct these data, Ridolfi (2019) compiled 26,332 wage observations retrieved from various archival sources.
Craftsmen are considered skilled workers, which explains their higher wages compared to laborers. We observe a stable trend in the data until 1600 and an increase afterward. The Black Death appears to have raised nominal wages, while the plague episodes of the 17th century alternated between positive and negative shocks. Because nominal wages are difficult to use for comparison, most of our analysis will instead rely on data related to the welfare ratio.
These data come from very different sources, computing a five-year moving average and correcting for spatial heterogeneity. Indeed, the distribution of wages across space is uneven. Some regions (Normandy, Alsace, and Île-de-France) supply most of the wage data, while other regions (Limousin and Franche-Comté) play only a marginal role.

Figure 2: Consumer Price Index, 1250-1860 (in sous tournois)



The consumer price index (CPI) is also drawn from Ridolfi (2019), whose work is based on Allen (2001)'s estimation strategy.[3] This series is constructed from 46,600 quotes for 12 commodities taken from various archival sources with wide spatial coverage (the Center and the South account for 42 percent of the data, the East for 31 percent, the North for 17 percent, and Paris for 10 percent) for the period 1250–1860 (Ridolfi, 2019). This measure is expressed in sous tournois and represents expenditure per person per year for a given basket. A consumption bundle is therefore used for this index. The CPI provides for 1,940 calories per day with enough protein, as well as other types of expenses such as clothing, lodging, and lighting.
This series has very similar behavior compared to nominal wages. We can observe that there were two main periods of inflation: one between 1500–1650 and another starting around 1700. We also highlight a small effect of the Black Death and a decrease during the plagues of the 17th and 18th centuries.

Figure 3: Welfare ratio, 1250-1860



The series on the welfare ratio uses the more recent data also provided by Ridolfi (2019) and contains the same three types of workers (agricultural laborers, building craftsmen, and building laborers), as well as the nominal wages for the period 1250–1860. In the same way as Allen (2001), the daily nominal wages and prices over the period are used to construct the series. Ridolfi (2019) divided the annual income of a four-member family by the family's annual expenses. This indicator can be compared to real wages, as underlined by Ridolfi (2017). We can observe that this ratio does not exhibit clear growth over time, while still being volatile. As with nominal wages, building craftsmen (skilled workers) possess a higher welfare ratio compared to laborers (unskilled workers). This ratio is rich in information, as it represents the real level of workers' income over time and allows for international comparison. We can identify that the Black Death had a temporary positive effect on this ratio, followed by a first decline until 1400 and a second one lasting until the early 17th century. The 17th- and 18th-century plague episodes appear not to affect the general trend deeply, compared to the Black Death. The general lesson from this figure is that the welfare ratio does not improve during the period observed, while remaining volatile.

[3]We do not transform the data here; instead, we keep them raw for the outlier methodology. Transformed data (rates and indices) can be found in Ridolfi (2019).

4.2 Database limitations

To conclude our exposé of the data, while we acknowledge the contribution and relevance of the Ridolfi (2019) database, we also recognize the limitations inherent in very long-term historical data analysis (Ridolfi, 2017) [4]. The aim of our work is not to call into question the database proposed by Ridolfi (2019), the relevance of which is well established. Nonetheless, very long-term analysis rarely yields fully consistent data, and we cannot ignore the consequences this may have on the empirical analyses.

More generally and according to the literature, all these historical data exhibit various limitations (Federico, Nuvolari, and Vasta, 2023, Ridolfi, 2024 and Ridolfi, 2023). First, these data are spatially constrained and may therefore present a sample selection issue due to the over-representation of certain regions. Second, the data also exhibit an uneven temporal distribution, alternating between periods of high and low data frequency, particularly during the early years of the database. Third, concerning wages, an occupational heterogeneity is also observed, with some types of workers accounting for a large amount. In particular, unskilled workers can be underrepresented and grouped into broad categories. Fourth, concerning CPI, it is clear that some choices have been made concerning the definition and the composition of the index. This matter is widely discussed in Ridolfi (2017) whose work is based on Allen (2001).

In addition to these limitations, there are broader ones that could directly impact our work. Variations in currencies and definitions of working days across primary sources make data harmonization challenging, and the methodological choices of data collectors can introduce biases (Ridolfi, 2021). Relying on country-level averages also reduces granularity, which may hinder our analysis of localized plague episodes. Being aware of these concerns and limitations is important for understanding the choices and corrections made by Ridolfi (2019) for each variable[5].

5 Empirical analysis

Using time-series data, we attempt to identify which events have affected the evolution of nominal wages, real wages, and prices since the thirteenth century. We are especially interested in the magnitude, length, and signs of the impact of plague pandemics and epidemics. For this purpose, we use the outlier methodology developed by Chen and Liu (1993) to detect the existence of possible breaks in the statistical series and their impacts[6].

To be more specific, the objective of the outlier method is to detect changes in data patterns that have a significant impact on the evolution of time series and identify the institutional, historical, or economic events responsible for these changes[7]. This method is well suited to historical analysis, because it examines non-simulated shocks. In statistics, an observation is considered exceptional when it deviates (positively or negatively) significantly from its mean

[4] In France, several databases are available Baulant (1971), d'Avenel (1894) and Labrousse (1932) among others. Labrousse criticised D'Avenel's databases, which he felt were sometimes approximate in time and space. One of the advantages of Ridolfi's work is that it takes into account all the existing bases and the weight of the various regions, thus providing a better interpretation of the mass of heterogeneous observations. Nonetheless, while analyses over shorter periods may yield divergent results, studies extending over very long timescales tend to reveal convergent trends, reinforcing the reliability of Ridolfi's work (Boyer, Jaoul-Grammare, and Rivot, 2020).

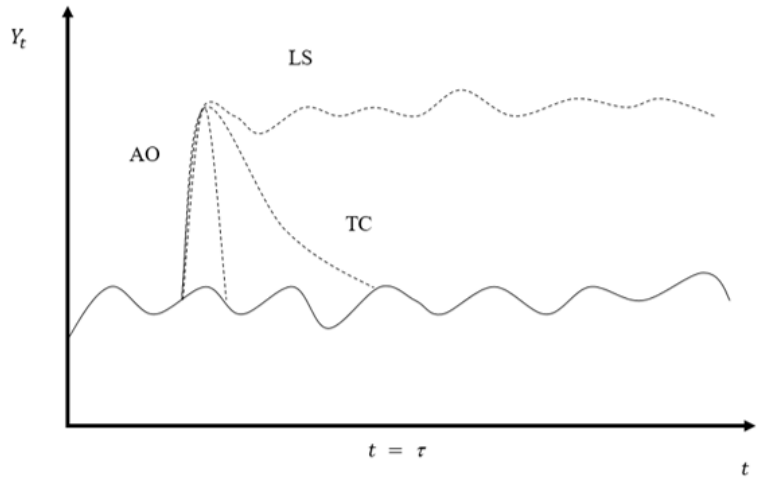
[5] For further insights into historical databases, we direct interested readers to Ridolfi (2024) on the topic of historical database

[6] The full extent of the methodology can be found in Appendix 1.

[7] Here, we are not discussing causality but instead manually mapping dates to potential events happening the same year as the outlier.

value or trend and does so with low frequency. From a purely statistical point of view, an extreme event is defined as a value two to three times the standard deviation of the series, while an atypical value is defined as a value well above three times the standard deviation of the series. We are only interested here in atypical or exceptional values[8]. The analysis of atypical points makes it possible to associate them with educational, economic, political, or financial events. The challenge is to identify these points, their possible causes, and their effect on the series. Accordingly, we define an $ARIMA(p, d, q)$ process fitted to our data (Diebolt and Darné, 2004). This allows us to detect outliers and their lasting effect by studying the residuals of the $ARIMA$ process. We apply the full automatic procedure suggested by Chen and Liu (1993).
As a result of this process, we detect outliers of various durations, signs, and amplitudes. The effect of outliers on a time series is varied, and the literature therefore groups outliers into four types. First, Innovative Outliers (IO), which represent temporary shocks that can be assimilated to "noise"; second, Additive Outliers (AO), which are associated with one-off exogenous changes; third, Temporary Changes (TC); and fourth, Level Shifts (LS), which represent ephemeral and permanent structural changes, respectively (Chen and Liu, 1993; Diebolt and Darné, 2004). An AO is generally considered to affect only one observation in the series, but not its future values. A TC causes a rapid change in the level of the series, which quickly returns to its evolutionary path. Finally, an LS affects the level of the series from a certain point onward definitively. These classifications are useful to understand the length of the impact of the concerned outliers. The outlier methodology gives us information not only about the duration, but also the sign and magnitude of the detected outliers[9].

Figure 4: The various outliers



The cliometric analysis performed here will detect changes in the series, and especially the impact of the plague over the period under study. To do so, we decided to split our data into four parts, as suggested by Ridolfi (2017). These parts are the following: before 1345 (pre-Black Death period); 1345–1550 (first Malthusian cycle after the Black Death); 1551–1690 (rise of the Great Inflation and stabilization); and 1691–1789 (pre-revolutionary period).

[8]This means that a slow-burning disease will not be detected by this approach
[9]The adjusted time series with outliers removed are presented in Appendix 2.

6 Results

6.1 Results summary

We attempt to associate each outlier with a known historical event. To do so we rely on various historical references[10]. For each plague-related outlier detected, we discuss their impact on the evolution of the series. We also investigate, when necessary, other contributing events that could be linked with plagues and serve as a precondition for their appearance. We distinguish between a permanent effect and a temporary one. A permanent effect indicates that the corresponding event has a lasting impact on the series, while a temporary effect impacts the series in the short to medium run. The outlier detection gives the following results[11].

During the pre-Black Death period, the observed impacts on our variables were primarily driven by wars and famines. Indeed, this was a period during which no plague outbreak appeared (Biraben, 1975). Depending on the variable and the year, the impacts of wars and famines were either permanent or temporary. In this time frame, we will specifically examine the episode of the Great Famine of 1315–1317 and underline the impact of the Franco-Flemish War.

Concerning the first Malthusian cycle, nominal wages, real wages, and prices were all affected by the Great Disease to varying degrees. Nominal wages generally experienced permanent positive impacts from the Black Death, while real wages and the CPI experienced short-term positive or negative effects; both cases will be discussed in detail later in the paper. Furthermore, we also detect the effects of famines during the Little Ice Age, as well as those of later plague outbreaks and major conflicts such as the Hundred Years' War.

For the rise of the Great Inflation period, the nominal wages of craftsmen, building laborers, and farm laborers were influenced by various temporary events in various ways. These events were mostly associated with local plague outbreaks, and the Thirty Years' War. Real wages were largely unaffected, except for farm laborers, who experienced the impacts of famines, plague, and war. The CPI, however, was more permanently and positively influenced by plague epidemics compared to other variables. This period, marked by high plague activity, will be further detailed later in the paper.

Over the pre-revolutionary period, in addition to famines (the Great Famine of 1709) and wars, nominal wages were affected by the plague of 1720. Real wages were also affected by the Great Famine of 1709 and appear to experience mostly short-term effects from famines and the Marseille plague. The Marseille plague is the only plague outbreak during this period; indeed, according to Biraben (1975), this period corresponds to a very low occurrence of plague outbreaks. Concerning the CPI, famines and wars are the main drivers of outlier events for this period.

The effects of plague outbreaks across periods differed between skilled and unskilled workers. Unskilled workers' real wages between 1280 and 1789 appear to follow the "iron law of wages". Indeed, while plague outbreaks have a strong short-term impact on real wages, these effects tend to dissipate over time, with wages returning to normal in the short to medium run, a less evident phenomenon for skilled workers.

The effect of plague pandemics and epidemics on nominal wages is significant and mostly posi-

[10] Concerning plague pandemics and epidemics we rely on: Biraben, 1975, Büntgen et al., 2012, Sardon, 2020. Concerning famines, we identify them using the following references: Alfani and Ó Gráda (2017); Alfani and Ó Gráda (2018); Béaur and Chevet (2017); Ljungqvist, Seim, and Collet (2024). We also identify high prices period using Béaur and Chevet (2017); Levasseur (1893). Concerning the various wars and revolts, we rely on very different sources: Anderson (2014); Bertrand (1988); Inglis-Jones (1994); Litzenburger (2020); Lodge (1931); Neillands (2001); Newfield (2009); Onnekink and Onnekink (2016); Rose (1908); Scott (2011); Sizer (2015); TeBrake (1993); Verbruggen (2002)

[11] All the detailed results, for each time a plague epidemic occurs, can be found in Appendix 2 for each period.

tive, with a Malthusian effect. However, we need to interpret these findings with caution, as the reaction of real wages to plague is less pronounced and more short-term, although still notable in response to the Black Death and some smaller epidemics of the 17th and 18th centuries.
Overall, price fluctuations are essentially due to plague outbreaks and famines, which are characterized by their scarcity.
Ultimately, it appears that plague affected all our variables. However, these effects vary, sometimes temporary and short-lived, and at other times permanent and structurally transformative. This will depend on the period, the variables, and the importance of the shocks.
More broadly, famines and wars have a recurrent impact on the series, which suggests that shocks often occur concurrently with other disturbances. In other words, we can emphasize that every plague outbreak may have occurred under varying environmental and institutional contexts, possibly intensified by other concurrent shocks[12]. Repeated and varied health shocks may have increased vulnerability to the consequences of subsequent epidemics. For example, meteorological issues could be harbingers of famines, which impact health and favor the diffusion of diseases (Campbell and Ludlow, 2020; Ó Gráda, 2007).

6.2 The pre-Black Death period

Table 1: Outliers detection 1280-1344 for nominal wages

Variables	Year	Type	t-stat	Effect duration	Sign	Event
Craftsmen's nominal wages	1301	LS	6	Permanent	(+)	Franco-Flemish War
	1341	AO	6.1	One-off	(+)	Hundred Years' War
Farm laborers' nominal wages	1291	LS	5.8	Permanent	(+)	End of the crusades
	1301	LS	9	Permanent	(+)	Franco-Flemish War
	1323	AO	4.8	One-off	(−)	Flemish peasant revolt
	1326	TC	3.2	Temporary	(+)	War of the Four Lords
Building lab. nominal wages	1313	AO	6.2	One-off	(+)	
	1323	TC	3.1	Temporary	(+)	Flemish peasant revolt

Table 2: Outliers detection 1280-1344 for CPI

Variables	Year	Type	t-stat	Effect duration	Sign	Event
CPI	1321	LS	8	Permanent	(+)	Cattle disease*
	1331	LS	5.4	Permanent	(+)	*Grande Cherté*
	1334	TC	3.5	Temporary	(+)	*Grande Cherté*

**There is no clear conclusion on whether France was still affected by cattle disease in 1319 and beyond, according to Newfield (2009). This can be interpreted as a delayed effect.*

[12]We do not establish any causal links between these events

Table 3: Outliers detection 1280-1344 for real wages

Variables	Year	Type	t-stat	Effect duration	Sign	Event
Craftsmen's welfare ratio	1303	AO	3.7	One-off	(+)	Little Ice Age beginning; Franco-Flemish War
	1316	AO	3.5	One-off	(–)	Great Famine
	1341	AO	3.6	One-off	(+)	Hundred Years' War
Farm lab. welfare ratio	1304	TC	3.6	Temporary	(–)	Little Ice Age beginning
	1316	AO	4.7	One-off	(–)	Great Famine
Building lab. welfare ratio	1316	AO	3.2	One-off	(–)	Great Famine

The pre-Black Death period is our first timeline, going from 1280 to 1344. During this time, we observe, in Tables 1, 2, and 3 that all our variables were affected by wars, conflicts, and famines[13]. The occurrence of these events is to be expected in a Malthusian and agrarian economy. As this period is not known to be prone to plague outbreaks, we did not expect to identify any particular epidemic-related events (Biraben, 1975). Wars appear to be the most recurrent events and have varied impacts on nominal and real wages, ranging from permanent to temporary, but mostly positive. The Great Famine of 1315–1317 is the main event of the period and resulted in high mortality. This famine was caused by a massive cattle disease and adverse weather conditions, with excessive rainfall negatively affecting crops (Alfani and Murphy, 2017; Campbell, 2010; Campbell and Ludlow, 2020; Kamen, 1968; Newfield, 2009).

This period is also well known as the beginning of the "Little Ice Age", which could have had an effect on the occurrence of back-to-back harvest shortfalls between 1315 and 1317 and possibly even before (Ó Gráda, 2007; Levasseur, 1893). This phenomenon covers all our data, beginning in the 14th century and ending in the 19th, and explains, in part, the high occurrence of famines throughout the various periods addressed in our work. The "Little Ice Age" could **also** have been a contributing factor in the spread of the Black Death and other epidemics within our time frame. Indeed, as previously discussed, extreme meteorological conditions and famines may facilitate disease transmission (Campbell and Ludlow, 2020). However, caution is needed, as underlined by Alfani (2010), since the interplay between weather, famines, institutions, and diseases is very complex and not straightforward. Due to the complex nature of this interplay, we will not make direct links between these events.

Concerning our variables, we observe the importance of the famine of 1315 to 1317, which negatively impacted all our real wage variables in the short term. The CPI is affected in the long run by the end or the delayed effect of the cattle disease and symbolizes a period of very high prices (*Grande Cherté*) and scarcity (Munro, 2004; Newfield, 2009). Nominal wages are strongly affected by multiple wars, especially the Franco-Flemish War, which had a strong long-term impact on all nominal wages and a short-term impact on craftsmen's real wages.

Regarding the direction of the effects, famines are mostly negatively correlated with real wages. Famines tend to reduce the labor supply, but they may also hinder productivity, which helps explain the associated decline in wages. In addition to these effects, we observe a positive impact of famines on the CPI, driven by food scarcity, which in turn negatively affects real wages.

We can conclude this period by noting that the Great Famine brought an end to a period of prosperity and weakened human health, paving the way for the later arrival of the Black Death.

[13]We can note the start of the Hundred Years' War at the end of the period

6.3 First Malthusian cycle

Table 4: Outliers detection 1345-1550 for nominal wages

Variables	Year	Type	t-stat	Effect duration	Sign	Event
Craftsmen's nominal wages	1350	LS	4.9	Permanent	(+)	Black Death
	1354	LS	4.6	Permanent	(+)	Black Death*
	1356	TC	5.6	Temporary	(+)	Hundred Years' War*
	1357	AO	9.3	One-off	(+)	Hundred Years' War*
	1361	AO	4.1	One-off	(–)	Plague outbreak
	1365	AO	5.4	One-off	(+)	Local plague outbreak
	1386	LS	3.8	Permanent	(–)	Hundred Years' War
	1431	LS	4.1	Permanent	(–)	*Les trois horribles*; Civil war; Famine
	1537	LS	4.3	Permanent	(+)	Local plague outbreak
	1547	TC	3.6	Temporary	(+)	Plague outbreak; High prices
Farm lab. nominal wages	1349	LS	5.9	Permanent	(+)	Black Death; Famine
	1420	TC	3.7	Temporary	(+)	Famine; *les trois horribles*; Civil war
Building laborers' nominal wages	1349	LS	4.3	Permanent	(+)	Black Death; Famine
	1350	AO	4.7	One-off	(+)	Black Death
	1352	LS	3.7	Permanent	(+)	Black Death
	1382	TC	4.2	Temporary	(–)	Plague outbreaks; Famine; Maillotins revolt
	1428	TC	3.8	Temporary	(+)	*Les trois horribles*; Civil war; Hundred Years' War
	1533	LS	6.4	Permanent	(+)	Famine*

**1354, 1356 and 1357 are outliers out of the Black Death period; however, the Black Death shock could still have a delayed impact here. 1533 is in the same situation with the famine ending* in 1532

Table 5: Outliers detection 1345-1550 for CPI

Variables	Year	Type	t-stat	Effect duration	Sign	Event
CPI	1347	TC	6.2	Temporary	(–)	Black Death; Famine
	1381	LS	4.6	Permanent	(+)	Tuchin revolts; Local plague outbreak
	1411	AO	5.1	One-off	(+)	Local plague outbreak; Civil war
	1468	TC	4	Temporary	(+)	Local plague outbreak

Table 6: Outliers detection 1345-1550 for real wages

Variables	Year	Type	t-stat	Effect duration	Sign	Event
Craftsmen's welfare ratio	1356	LS	3.6	Permanent	(+)	Hundred Years' War*
	1357	AO	5.4	One-off	(+)	Hundred Years' War*
	1365	AO	4	One-off	(+)	Local plague outbreak
	1372	TC	4.3	Temporary	(+)	Hundred Years' War; Local plague outbreak
Farm lab. welfare ratio	1349	AO	4.6	One-off	(+)	Black Death; Famine
Building lab. welfare ratio	1351	AO	5.4	One-off	(–)	Black Death

**1356 and 1357 are outliers out of the Black Death period; however, the Black Death shock could still have a delayed impact here.*

In the second timeline, we examine the first Malthusian cycle, which includes the Black Death, the Hundred Years' War, various famines, and later plague outbreaks. As we are interested in the impact of plague outbreaks, we will specifically focus on the Black Death's various effects on our variables.

Many studies have shown that both nominal and real wages rose during the Black Death (Pamuk, 2007; Voigtländer and Voth, 2013, etc.). We see this trend to some extent in our results, as illustrated in Tables 4 and 6. The observed increase in nominal wages during the Black Death period presents very different characteristics across all types of workers. In detail, we observe that for craftsmen's nominal wages, this effect is long-term but diminishes over time (see Figure 5), returning practically to normal by the middle of the 15th century. For farm laborers, the effect of the level shift remains elevated for longer but also appears to diminish during the mid-15th century (see Figure 6). Concerning building laborers' nominal wages, the Black Death appears to have had a long-term effect with a permanent impact (see Figure 7). Real wages, for their part, are not permanently affected by the Black Death. The craftsmen's welfare ratio is the only variable that is permanently affected by a delayed effect of the Black Death (see Figure 9), while other real wages return to their counterfactual trends very quickly. This shows that the Black Death rarely affected real wages in the long run, a point previously discussed in the literature (see Figures 10 and 11). These findings indicate that skilled workers' real wages

improved over the long run, but not those of unskilled workers. This phenomenon may reflect the scarcity of skilled workers compared to unskilled ones, who are more easily substitutable. This also confirms that not all labor shortages were the same, as Cohn (2007) has underlined.
Lastly, the CPI series (see Table 5 and Figure 8) responds to the Black Death in 1347 with medium-term negative impacts, an effect that could correspond to weak demand. The CPI reaction to the Black Death contrasts with the findings in the literature on England previously discussed. Indeed, the Black Death appears to have had a deflationary effect, in contrast to the inflationary phenomenon discussed earlier. We can cautiously interpret these results by hypothesizing that the initial effect of the Black Death in 1347 was a significant reduction in demand. By comparison, the 1381 Tuchin Revolts and the plague outbreak in the East of France seem to have had a more prolonged positive effect on prices than the Black Death (Biraben, 1975). This is not surprising, as the post-Black Death period is known to have been marked by price fluctuations. While being affected by the Black Death, other types of events, such as wars and later local plague outbreaks, also impacted these results positively, with varying durations. These observations highlight the effectiveness of the outlier methodology in isolating the positive impact of the Black Death, while providing a counterfactual to identify its duration and offering hints about its magnitude. Our findings across the three types of workers' nominal and real wages show that the persistence of epidemiological shocks is not straightforward. Voigtländer and Voth (2013) suggest that the Black Death was a significant event for the improvement in wages, which appears to be permanent through the "horsemen effects". Here, our results are not that clear. Even if there is a persistence of the effect of the Black Death on nominal wages for all workers, this is not confirmed for real wages, as a long-term positive impact was observed only among craftsmen. One particularly interesting aspect is the tendency for the Black Death's positive effects on real wages for unskilled workers to diminish in the short term, confirming the well-known "iron law of wages" for this group. This finding aligns with the Middle Ages roots of Little Divergence, as France did not maintain high real wages for an extended period. Indeed, according to the literature, England kept high real wage levels for a long time (Allen, 2001; Pamuk, 2007), creating a gap in income between the two countries and favoring the economic development of the northern part of Europe. Overall, these results support the epidemiological hypothesis of the roots of the Little Divergence, emphasized by, Pamuk (2007) while refining the view of a uniform increase in wages (Prados de la Escosura and Rodríguez-Caballero, 2022).
After the Black Death, other plague outbreaks appeared. Nominal wages were affected by plague in 1361, 1365, 1382, 1468, 1537 and 1547 in very different ways, permanently as in 1537 or temporarily as in 1382. The direction of the effect also varies, although it appears to be predominantly positive. Real wages, however, were less impacted by plague outbreaks later on, except for the 1365 temporary positive effect on craftsmen welfare ratio.
We emphasize the impact of the Hundred Years' War, which hit France from 1336 to 1450 and is symbolized by the presence of "*les trois horribles*" and specific important battles in our results. Indeed, this period of political and monetary instability greatly impacted France, keeping wages low in comparison to England (Ridolfi, 2019). During the pre-Black Death period, food shortages and weather variability were significant, and this remains the case here, with additional factors such as wars and institutional instability. These conditions created a fertile ground for major pandemics like the Black Death or major famines to appear (Pfister, Schwarz-Zanetti, and Wegmann, 1996).

6.4 Rise of the Great Inflation

Table 7: Outliers detection 1551-1690 for nominal wages

Variables	Year	Type	t-stat	Effect duration	Sign	Event
Craftsmen's nominal wages	1642	TC	4.2	Temporary	(+)	Thirty Years' War; Local plague outbreak
	1650	LS	4.1	Permanent	(+)	Local plague; Famine
	1672	LS	3.6	Permanent	(–)	Franco-Dutch war
Farm lab. nominal wages	1634	TC	3.7	Temporary	(–)	Thirty Years' War; Plague epidemics
	1647	TC	4.1	Temporary	(–)	Local plague epidemics; Thirty Years' War
	1682	TC	3.4	Temporary	(–)	
Building lab. nominal wages	1631	TC	3.3	Temporary	(+)	Thirty Years' War; Plague epidemics; Famine
	1658	TC	3.4	Temporary	(+)	Franco-Spanish War

Table 8: Outliers detection 1551-1690 for CPI

Variables	Year	Type	t-stat	Effect duration	Sign	Event
CPI	1616	LS	5.2	Permanent	(+)	Local plague outbreak
	1617	AO	4.6	One-off	(+)	Local plague outbreak
	1656	LS	4.8	Permanent	(+)	Local plague outbreak

Table 9: Outliers detection 1551-1690 for real wages

Variables	Year	Type	t-stat	Effect duration	Sign	Event
Craftsmen's welfare ratio - No outliers detected						
Farm laborers' welfare ratio	1586	LS	3.9	Permanent	(–)	Famine; Plague outbreak
	1622	LS	3.4	Permanent	(–)	Thirty Years' War; Local plague outbreak
Building laborers' welfare ratio - No outliers detected						

In this third timeline, the rise of the Great Inflation, we detect various outliers in Tables 7 to 9. Starting with nominal wages, we find that they were influenced by the Thirty Years' War through temporary and exceptional events of varying nature (Kamen, 1968). In addition, nominal wages were affected by local plague epidemics, particularly during the period of intense plague activity in France between 1625 and 1649. According to Alfani (2013), this period is considered the worst plague outbreak after the Black Death. These epidemics appear to have had impacts on nominal wages ranging from temporary to relatively permanent, with moderate magnitude and varying signs (see Figures 12 to 16).

The volatility of the effect depends on the strength of the Malthusian effect[14], but it can also be attributed to progress in containment measures. As Alfani and Percoco (2019) highlighted, the various plague epidemics of the 17th century do not exhibit a definite positive pattern, as the Black Death did during the 14th century. Alfani (2022) also argues that the 17th-century plague epidemics occurred in very different initial cultural and institutional contexts. Indeed, the preparedness and response to diseases greatly improved between the two periods, as did the control of the laboring class, which had been tightened after the Black Death (Cohn, 2007). This deep change in infectious disease management and institutional structure can explain the short-term and varied effects compared to the Black Death period. All these arguments help us understand why this impact is not comparable to the massive positive impact of the Black Death, but is rather a more transient impact, sometimes positive, sometimes negative, depending on the date and the type of workers studied.

These interpretations of nominal wage movements need to be nuanced, as only the welfare ratio of farm laborers responds to epidemics, the effects of which are often diluted by other events. Indeed, famines and wars have also contributed to the negative and long-term impact on farm laborers' welfare ratio, alongside plague outbreaks. This reinforces the argument that plague containment and management improved during this period, as most welfare ratios remain unaffected.

Finally, observe that the CPI is mostly positively and permanently affected by plague epidemics, likely due to the scarcity associated with these events. This is in accordance with the rise of the Great Inflation known in this period.

Here, as in the previous period, famines play a significant role in the movement of our macroeconomic variables. They consistently appear to interplay with outbreaks of plague during this period. Our results indicate that, during several years, multiple events occurred simultaneously, reinforcing the notion of a strong interplay between these shocks.

[14]Some of the plague outbreaks may have been very localized, according to Biraben (1975)

6.5 Pre-revolutionary period

Table 10: Outliers detection 1691-1789 for nominal wages*

Variables	Year	Type	t-stat	Effect duration	Sign	Event
Craftsmen's nominal wages	1693	TC	3.9	Temporary	(+)	Famine
	1699	AO	3.7	One-off	(–)	
	1716	LS	4.5	Permanent	(+)	
	1753	AO	6.5	One-off	(+)	
	1782	AO	3.2	One-off	(+)	American Revolutionary War
Farm laborers' nominal wages	1718	LS	4.7	Permanent	(+)	Famine
	1730	AO	3.5	One-off	(+)	
	1762	TC	4.6	Temporary	(–)	Seven Years' War
	1766	AO	3.4	One-off	(–)	High prices
	1789	AO	3.7	One-off	(+)	Famine
Building laborers' nominal wages	1720	LS	5.5	Permanent	(+)	Marseille Plague
	1733	TC	3.3	Temporary	(+)	Poland succession war
	1741	AO	3.8	One-off	(+)	Famine; Austrian war
	1786	AO	3.2	One-off	(+)	Local plague outbreak

**In this table, some outliers remain unidentified or are linked to events different from those central to this study, such as the John Law system between 1716 and 1720 or a modification of the taxation system (Hamilton, 1937).*

Table 11: Outliers detection 1691-1789 for CPI

Variables	Year	Type	t-stat	Effect duration	Sign	Event
CPI	1739	TC	9.9	Temporary	(+)	Famine
	1745	TC	3.7	Temporary	(–)	Austrian war
	1748	LS	3.9	Permanent	(+)	Famine*; Austrian war
	1750	AO	4.6	One-off	(+)	

**1748 is an outlier, happening right after the 1747 famine; however, the 1747 famine could still have a delayed impact here.*

Table 12: Outliers detection 1691-1789 for real wages

Variables	Year	Type	t-stat	Effect duration	Sign	Event
Craftsmen's welfare ratio	1709	TC	6.4	Temporary	(–)	Famine
	1720	AO	4.1	One-off	(–)	Marseille plague
	1753	AO	5.4	One-off	(+)	Famine
	1760	LS	4.7	Permanent	(–)	Seven Years' War
Farm lab. welfare ratio	1709	TC	4.2	Temporary	(–)	Famine
Building lab. welfare ratio	1709	TC	5.5	Temporary	(–)	Famine
	1715	TC	3.4	Temporary	(+)	

In this fourth timeline, we observe various events, in Tables 10 to 12, with both permanent and temporary effects on our variables. Concerning nominal wages, we identify the impact of the Marseille plague (1720) on the building laborers' nominal wage series. This impact is a positive and long-term effect of this plague episode on building laborers' nominal wages, similar to the previously identified effect of the Black Death for this type of worker (see Figure 17). Other types of nominal wages are not affected by any plague, as this period marked a time when plagues were no longer spreading and had practically disappeared (Biraben, 1975). Instead, they were influenced, mostly positively and temporarily, by other factors such as wars and famines.
For real wages, only craftsmen are affected, negatively and temporarily, by the Marseille plague (see Figure 18). The welfare ratios of other types of workers are not affected in any way by epidemics.
As previously, we detect very different results for different types of workers. The positive long-term effect found for building laborers' nominal wages is not consistent with the results in the literature on the negative effects of 17th-century plague episodes (Alfani, 2022). However, skilled workers' real wages are differently and negatively affected by the Marseille plague. This means that the reaction of craftsmen's real wages is consistent with the literature. Specifically, the building laborers' nominal wage reaction is of Malthusian origin, whereas this is not the case for craftsmen's real wages. Indeed, for this plague episode, there were very different initial conditions and institutional reactions compared to the Black Death period (Alfani, 2022). For example, the authorities in Marseille attempted to contain the plague through the implementation of *cordons sanitaires*, a strategy that differed from the one employed during the Black Death (Signoli, 2022). The authorities' adaptation and institutional learning in infectious disease management help explain, in part, the absence of identifiable outliers in nominal or real wages related to plague outbreaks for other workers during this period. Indeed, more effective containment strategies likely mitigated the economic impact of these outbreaks (Alfani, 2022).
In addition to the impact of infectious diseases, real wages were also significantly affected by the Great Famine of 1709, with a negative temporary effect comparable to, and even greater than, that of the Great Famine of 1315–1317. They are also still impacted by many wars, especially the Seven Years' War, which had a permanent negative effect on the craftsmen's welfare ratio. Here, too, we may intuit a link between these various events.
Prices tend to increase primarily because of the high occurrence of famines and wars, which is surely due to the high level of scarcity during this period.

7 Conclusion

This paper aims to analyze the impact of plague pandemics and large-scale epidemics on the French economy over a long historical period. We have focused in particular on nominal and real wages, and prices, using long-term time series data. In the literature, the impact of infectious diseases on wages and prices is generally ambiguous, depending on the context, epidemiological parameters, and the period.

The originality of our paper lies in the use of a very long time series of data from various sources, covering the period from 1280 to 1789. To the best of our knowledge, part of this dataset has not been previously employed in historical analyses of plague outbreaks. Based on these data, we conducted a cliometric analysis using the outlier methodology.

Our findings show that nominal wages are significantly and variably affected by plague in both the short and long term, while also responding to other events such as famines and wars. Real wages, by contrast, tend to exhibit a more short-term response to plague pandemics and epidemics. Occupation emerges as an important factor in wage analysis, adding nuance to the idea of a uniform reaction to plague outbreaks. Prices respond strongly to famines and the resulting scarcity, while plague outbreaks also have a notable effect across various periods.

In the context of the Black Death, the short- to medium-term positive effect aligns with the hypothesis that the Little Divergence could have begun with the Black Death. However, our findings show that France's real wages returned quickly to previous levels, contradicting the idea that there was a permanent positive effect of the Black Death on real wages. In the end, while we demonstrate the importance of plague outbreaks, it appears that institutional events, wars, and famines are also essential in explaining the long-term and permanent movements of our macroeconomic variables. We emphasize the interplay between these events. Building on these findings, future research could further explore the consequences of food shortages and agricultural shocks and their long-term effects.

Appendix 1: the outlier procedure

In this appendix, we provide a detailed explanation of the outlier detection and correction procedure used in this paper. Outliers can be defined as rare and significant temporary or permanent shocks that influence a specific time series (Diebolt and Darné, 2004). To identify them and their effect, we adopt the procedure developed by Chen and Liu (1993) of iterative detection and adjustment to estimate their impact and obtain the figures in Appendix 2. We apply this methodology using the R package *tsoutliers* very similar to TRAMO[15].

We introduce this technique by following Diebolt and Darné (2004) description. Starting with an example of a univariate time series y_t^* which follows an $ARIMA(p,d,q)$ process:

$$y_t^* = \frac{\theta(B)}{\alpha(B)\phi(B)} a_t, \text{t=1,...,n} \tag{1}$$

where n is the number of observations of a series, B is the lag operator, a_t is a white noise process, and $\alpha(B)\,\phi(B), \theta(B)$ are the lagged polynomials with orders d, p and q, respectively. The outliers can be represented using regression polynomials as follows:

$$y_t = y_t^* + \sum_I \omega_i \nu_i(B) I_t(\tau) \tag{2}$$

where y_t^* is following an $ARIMA$ process, $\nu_i(B)$ is the polynomial characterizing the outlier occurring at time $t = \tau$, ω_i indicates the outlier impact on the series, and $I_t(\tau)$ is an indicator function with a value of 1 at $t = \tau$ and 0 otherwise.

In this paper, we used three main outlier types:

- **Additive Outliers (AO):** Only affect a single observation: $\nu_i(B) = 1$.
- **Level Shifts (LS):** Affect all observations by a constant value: $\nu_i(B) = 1/(1-B)$.
- **Temporary Changes (TC):** A rapid change that returns slowly to the previous level, depending on a decay parameter: $\nu_i(B) = 1/(1-\delta B)$, where $0 < \delta < 1$.

Each type of outlier reflects a different phenomenon in the time series. Additive Outliers (AO) represent an exogenous and isolated deviation that only affect an individual observation without altering the rest of the series. In contrast, Temporary Changes (TC) and Level Shifts (LS) are structural shifts, with TC reflecting short-lived deviations that decay over time, and LS indicating a permanent change in the level of the series.

We fit an $ARIMA$ model to y_t^* in (1), and obtain residuals as:

$$\hat{a}_t = \pi(B) y_t \tag{3}$$

where $\pi(B) = \frac{\alpha(B)\phi(B)}{\theta(B)} = 1 - \pi_1 B - \pi_2 B^2 - ....$

For each outlier in (2), the residuals are:

$$\text{AO:} \quad \hat{a}_t = a_t + \omega_1 \pi(B) I_t(\tau) \tag{4}$$

$$\text{LS:} \quad \hat{a}_t = a_t + \omega_2 \frac{\pi(B)}{(1-B)} I_t(\tau) \tag{5}$$

$$\text{TC:} \quad \hat{a}_t = a_t + \omega_3 \frac{\pi(B)}{(1-\delta B)} I_t(\tau) \tag{6}$$

These expressions are regression model for $\hat{a}_t$ where:

$$\hat{a}_t = x_{i,t}\omega_i + a_t, \;\; i\text{=1,2,3} \tag{7}$$

with the following conditions:

[15]Some notable applications of this technique are Diebolt and Darné, 2004; Diebolt and Hippe, 2022

- For all i and $t < \tau$: $x_{i,t} = 0$
- For all i and $t = \tau$: $x_{i,t} = 1$
- For $t > \tau$ and $k \geq 1$:

$$x_{1,t+k} = -\pi_k \quad \text{(AO)}$$

$$x_{2,t+k} = 1 - \sum_{j=1}^{k} \pi_j \quad \text{(LS)}$$

$$x_{3,t+k} = \delta^k - \sum_{j=1}^{k-1} \delta^{k-j}\pi_j - \pi_k \quad \text{(TC)}$$

The test statistics for each outlier type are given by:

$$\text{AO:} \quad \hat{\tau}_1(\tau) = \frac{\frac{\hat{\omega}_1(\tau)}{\hat{\sigma}_a}}{\left(\sum_{t=1}^{n} x_{1,t}^2\right)^{1/2}} \tag{8}$$

$$\text{LS:} \quad \hat{\tau}_2(\tau) = \frac{\frac{\hat{\omega}_2(\tau)}{\hat{\sigma}_a}}{\left(\sum_{t=1}^{n} x_{2,t}^2\right)^{1/2}} \tag{9}$$

$$\text{TC:} \quad \hat{\tau}_3(\tau) = \frac{\frac{\hat{\omega}_3(\tau)}{\hat{\sigma}_a}}{\left(\sum_{t=1}^{n} x_{3,t}^2\right)^{1/2}} \tag{10}$$

with $\hat{\omega}_i(\tau)$ equal to:

$$\hat{\omega}_i(\tau) = \frac{\sum_{t=\tau}^{n} \hat{a}_t x_{i,t}}{\sum_{t=\tau}^{n} x_{i,t}^2} \quad \text{for } i\text{=1,2,3}$$

Here, $\hat{\omega}(\tau)(i = 1 - 3)$ denotes the estimated magnitude of the outlier's effect occurring at time $t = \tau$ and $\hat{\sigma}_a$ is an estimate of the variance of the residual process.

An outlier is identified at $t = \tau$ when $\hat{\tau}_i(\tau)$ exceeds a critical value. The critical value used by the tsoutliers package is simulation-based and depends on the length of the time series. The type of outlier is chosen based on the maximum significance:

$$\max|\hat{\tau}_i(\tau)| = \hat{\tau}_{\max} \tag{11}$$

If an outlier is detected, the observation y_t is adjusted to obtain y_t^* by:

$$y_t^* = y_t - \hat{\omega}_i \nu_i I_t(\tau) \tag{12}$$

To select the appropriate outlier, we use the "bottom-up" method. It begins by identifying the outlier with the highest t-statistic and testing its significance in the model. If it is significant, it is kept; otherwise, it is removed. The next most significant outlier is then added along with the first one, and its effect is evaluated not only for its own significance but also for any impact it may have on the significance of previously included outliers. If adding a new outlier causes any confirmed outliers to become insignificant, the new one is discarded. This process continues until no further outliers can be added without compromising the significance of the existing set, resulting in a highly selective model that includes only the most impactful outliers. We display our outliers corrected series in Appendix 2.

As discussed earlier, the previously described procedure is implemented in R using the package *tsoutliers*, where we select the most restrictive criterion to detect outliers and automate the entire process[16].

[16]Replication package can be asked to the corresponding author

Appendix 2: corrected series

Outliers detection procedure for nominal wages during the Black Death period

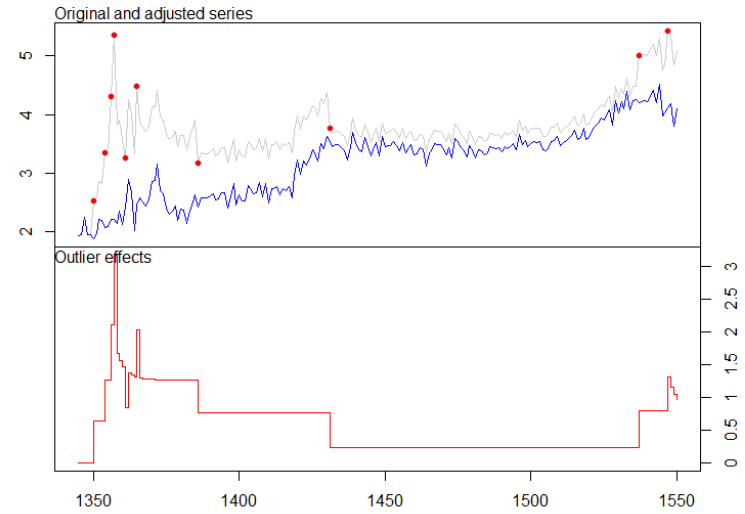


Figure 5: Outliers effects and detection procedure for nominal wages of craftsmen during the period 1345 to 1550 (ARIMA (0,1,1))

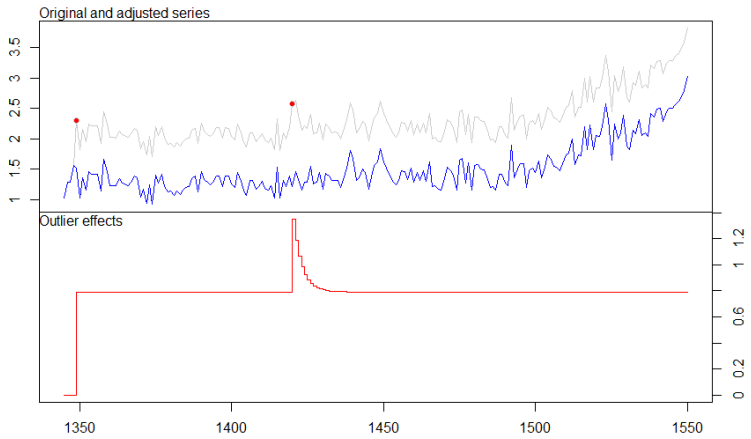


Figure 6: Outliers effects and detection procedure for nominal wages of farm laborers during the period 1345 to 1550 (ARIMA (1,1,1))

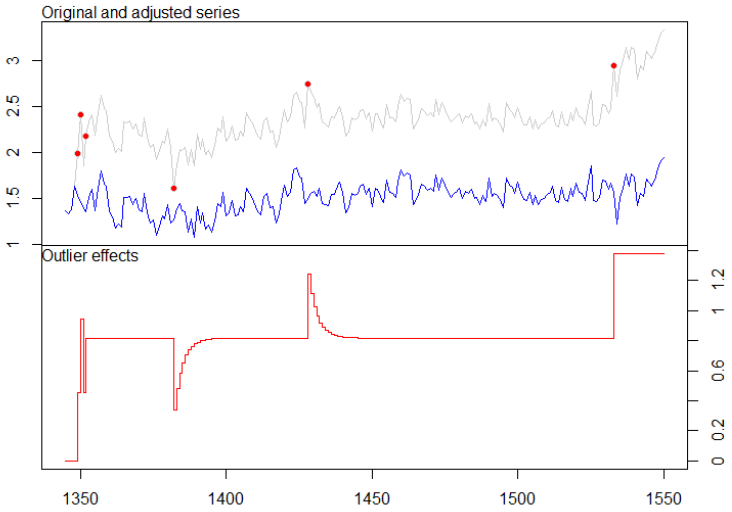


Figure 7: Outliers effects and detection procedure for nominal wages of building laborers during the period 1345 to 1550 (ARIMA (1,1,1))

Example of outliers detection procedure for CPI during the Black Death period

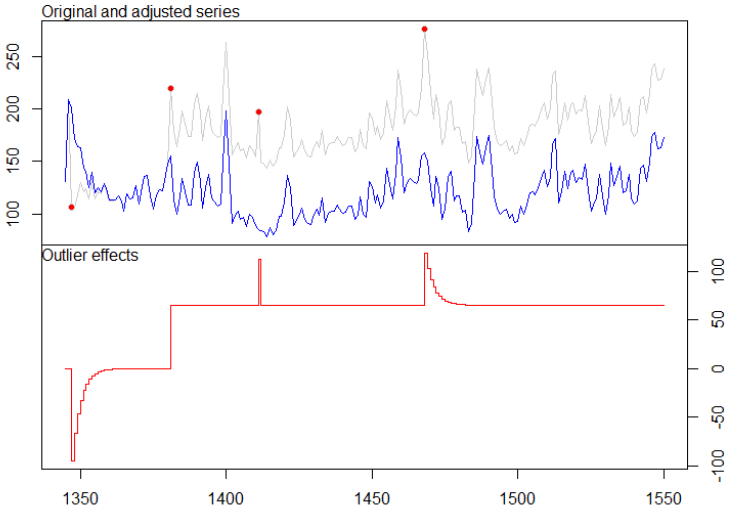


Figure 8: Outliers effects and detection procedure for CPI during the period 1345 to 1550 (ARIMA (3,1,2))

Example of outliers detection procedure for welfare ratio during the Black Death period

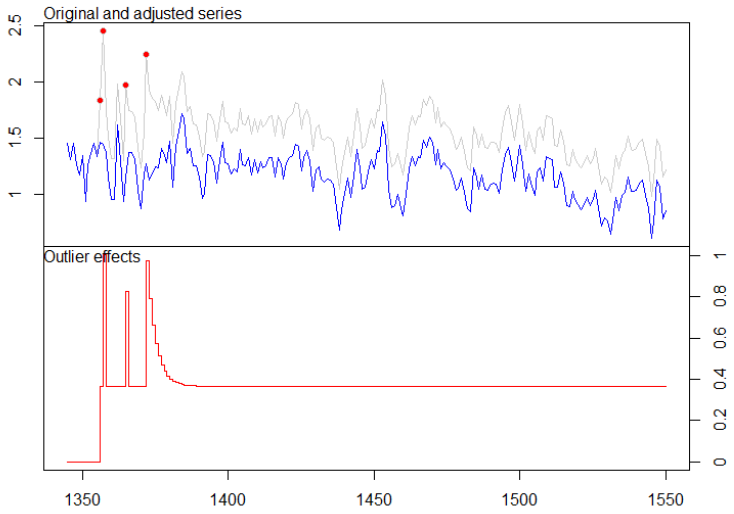


Figure 9: Outliers effects and detection procedure for welfare ratio of craftsmen during the period 1345 to 1550 (ARIMA (1,1,2))

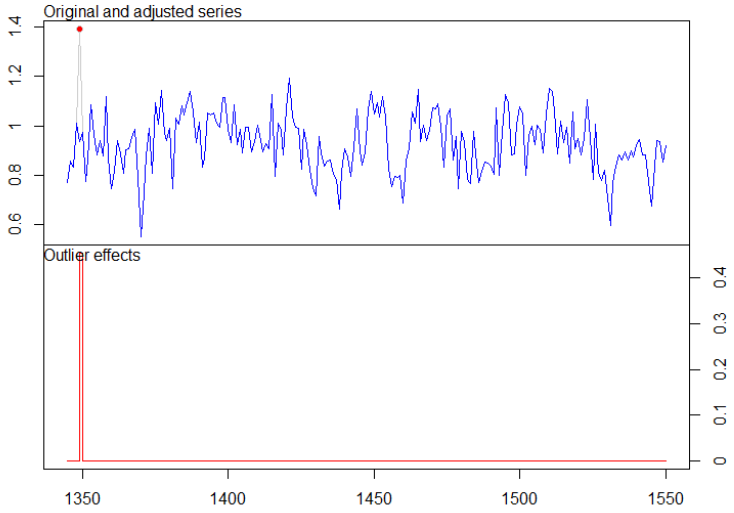


Figure 10: Outliers effects and detection procedure for welfare ratio of farm laborers during the period 1345 to 1550 (ARIMA (1,0,1))

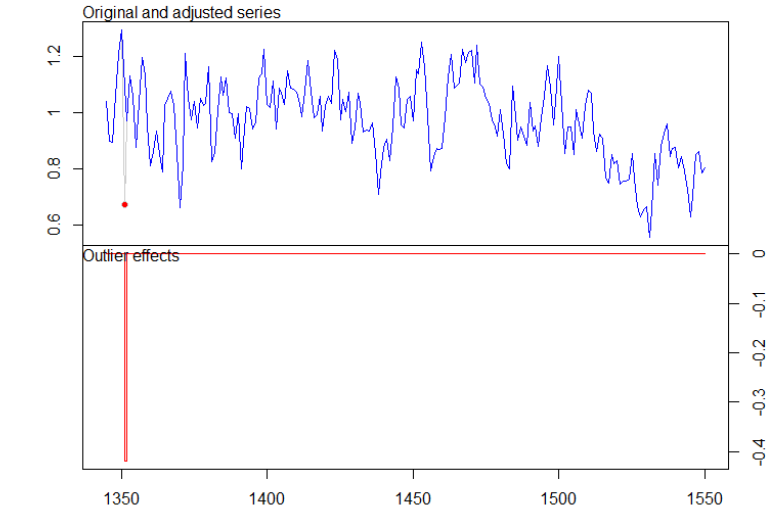


Figure 11: Outliers effects and detection procedure for welfare ratio of building laborers during the period 1345 to 1550 (ARIMA (0,1,2))

Example of outliers detection procedure for nominal wages during the 17th century plague period

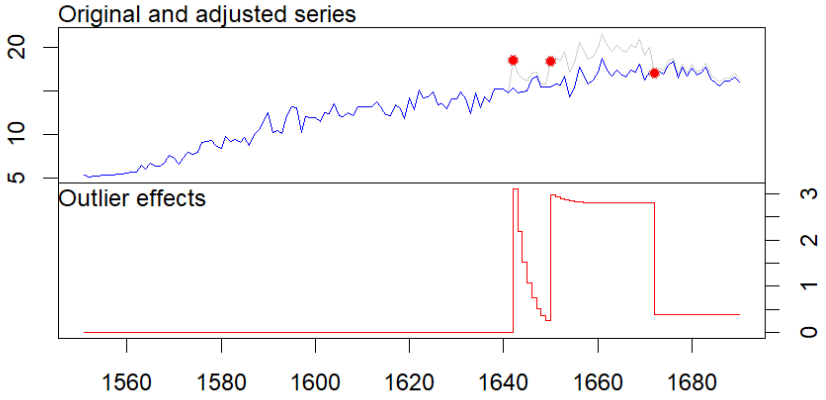


Figure 12: Outliers effects and detection procedure for nominal wages of craftsmen during the period 1551 to 1690 (ARIMA (0,1,1))

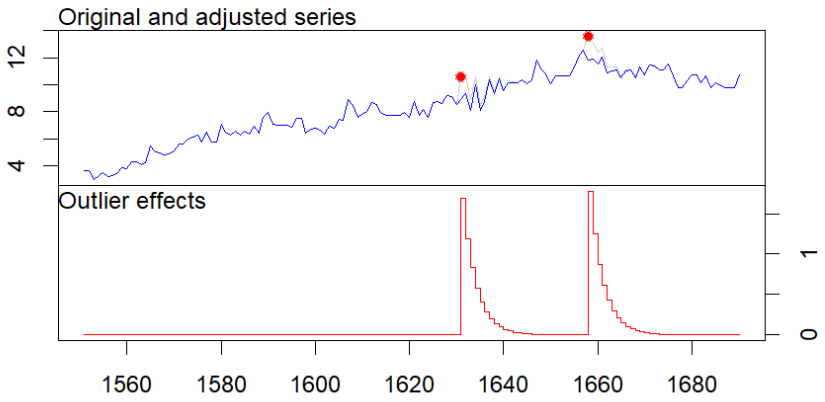


Figure 13: Outliers effects and detection procedure for nominal wages of building laborers during the period 1551 to 1690 (ARIMA (0,1,1))

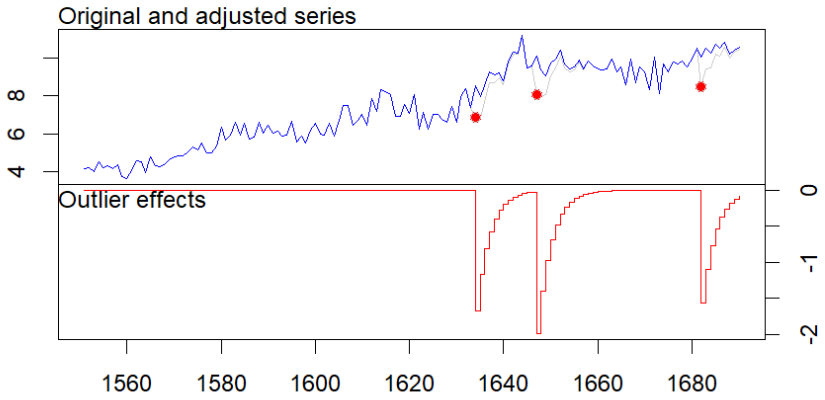


Figure 14: Outliers effects and detection procedure for nominal wages of agricultural laborers during the period 1551 to 1690 (ARIMA (1,1,1))

Example of outliers detection procedure for CPI during 17th century plague period

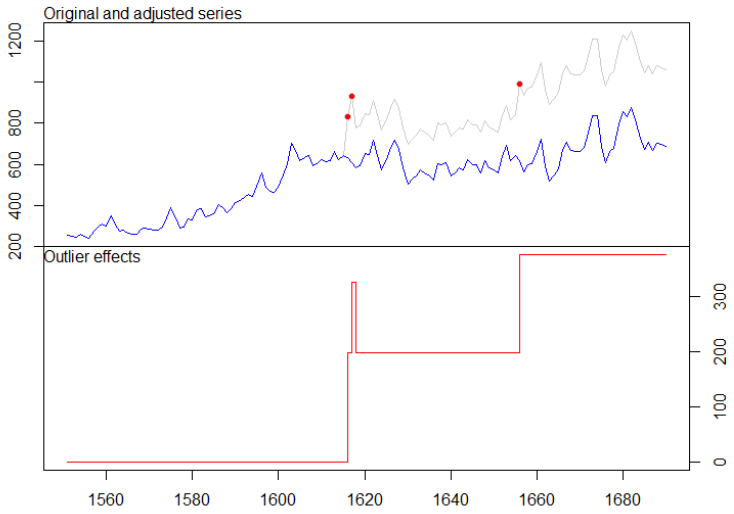


Figure 15: Outliers effects and detection procedure for CPI during the period 1551 to 1690 (ARIMA (2,1,2))

Example of outliers detection procedure for welfare ratio during 17th century plague period

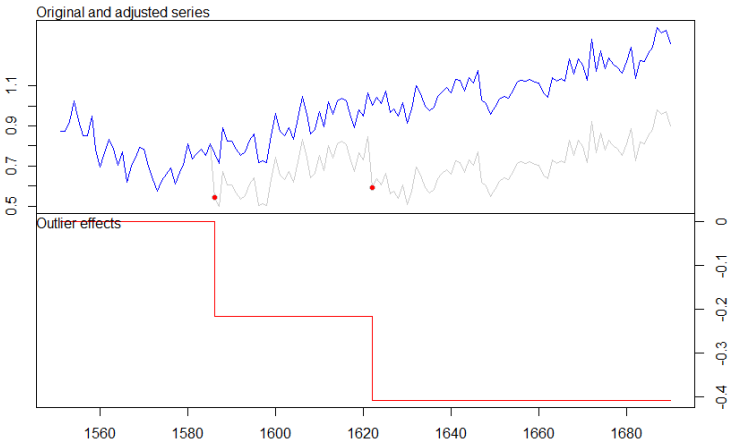


Figure 16: Outliers effects and detection procedure for welfare ratio of agricultural laborers during the period 1551 to 1690 (ARIMA (1,1,1))

Example of outliers detection procedure for nominal wages during the Marseille plague period

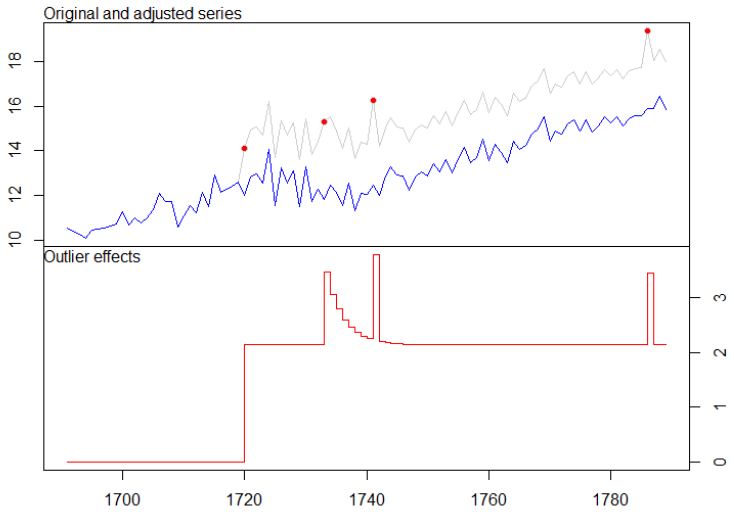


Figure 17: Outliers effects and detection procedure for nominal wages of building laborers during the period 1691 to 1789 (ARIMA (1,1,1))

Example of outliers detection procedure for welfare ratio during the Marseille plague period

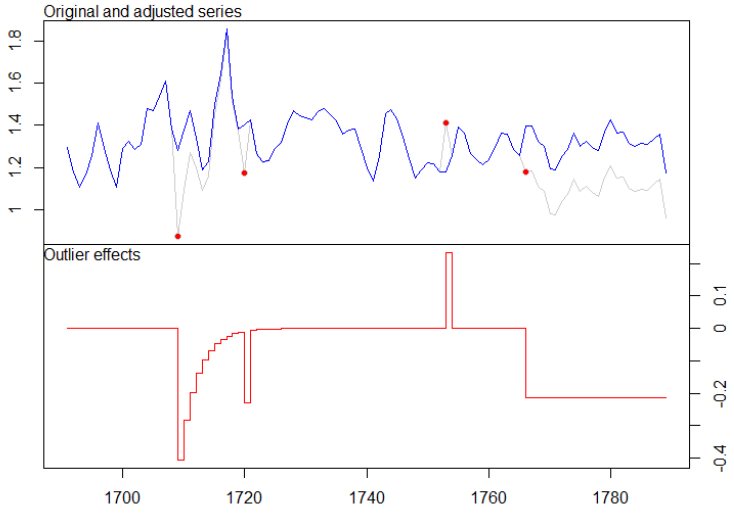


Figure 18: Outliers effects and detection procedure for welfare ratio of craftsmen during the period 1691 to 1789 (ARIMA (2,0,2))

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