Longer-run economic consequences of pandemics*

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December 2020

Abstract

What are the medium- to long-term effects of pandemics? How do they differ from other economic disasters? We study major pandemics using the rates of return on assets stretching back to the 14th century. Significant macroeconomic after-effects of pandemics persist for decades, with real rates of return substantially depressed. The responses are in stark contrast to what happens after wars. Our findings also accord with wage and output responses, using more limited data, and they are consistent with the neoclassical growth model: capital is destroyed in wars, but not in pandemics; pandemics instead may induce relative labor scarcity and/or a shift to greater precautionary savings.

JEL classification codes: E43, F41, I10, N10, N30, N40, O40.

Keywords: pandemics, wars, depressions, real interest rate, natural rate, local projections.

*We are grateful to the editor and three anonymous referees for helpful suggestions. We thank Robert Allen, Gregory Clark, Paul Schmelzing, and the Bank of England for making their datasets publicly available. All errors are ours. The views expressed herein are solely those of the authors and do not necessarily represent the views of the Federal Reserve Bank of San Francisco or the Federal Reserve System.

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1. Introduction

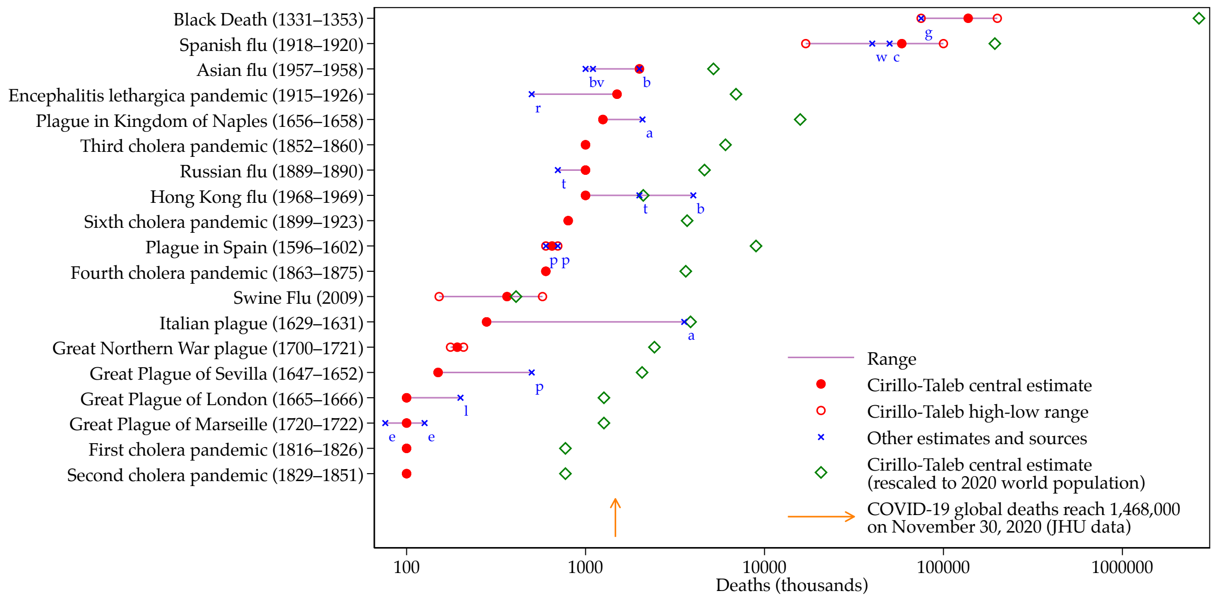
How should we think about the medium- to long-term macroeconomic effects of pandemics? The first instinct is to draw from the experience of previous natural disasters and armed conflicts, for which the twentieth century provides ample evidence. That instinct turns out to be wrong. In this paper we use the history of major pandemics, major wars, and the rates of return since the 14th century to shed light on this problem.

In many studies of pandemics, analysis has understandably focused on short-term impacts. Even then, direct measures based on data from past episodes are not generally available (e.g., in the U.S., Meltzer, Cox, and Fukuda, 1999). An alternative would be to look at microeconomic outcomes of a given population in episodes for which high-quality administrative data are available (e.g., in Sweden, Karlsson, Nilsson, and Pichler, 2014).

Absent such data, economic historians have to use more aggregated data at the regional or national level to study the relationship between pandemic incidence and economic outcomes (e.g., the 1918 flu epidemic across U.S. states Brainerd and Siegler, 2003; Barro, Ursúa, and Weng, 2020). But again, most historical studies have typically focused on one event in one country or region and have traced local outcomes for up to a decade at most.

Of course, the most devastating pandemic of the last millennium, the Black Death, has attracted a great deal of scholarly attention. Economists and historians debate its pivotal role in economic, social, and political change, particularly in Europe. Events such as the Peasants' Rebellion in England feature centrally in a narrative of rising worker power, and the data speak to an emergence of labor scarcity seen in a positive deviation in the path of real wages all across Europe. For example, this shock left England with a 25% to 40% drop in labor supply, a roughly 100% increase in real wages, and a decline in rates of return on land from about 8% to 5% (Clark, 2007, 2010). In the very long run, this wage shock may have been a turning point in the trajectory of European growth, potentially triggering a switch to urbanization and growth on the road to the Industrial Revolution, as argued by Voigtländer and Voth (2012). But our focus is on a shorter timescale–decades not

Figure 1: *Nineteen major pandemic events from the past with at least 100,000 estimated deaths*



Notes: The main data are taken from the recently published study of Cirillo and Taleb (2020). See the references therein. Additional estimates of pandemic mortality are taken from: (g) George M. Gould and Walter L. Pyle. 1896. *Anomalies & Curiosities of Medicine*. New York: Bell; (w) Wang-Shick Ryu. 2017. *Molecular Virology of Human Pathogenic Viruses*. Amsterdam: Academic Press. (c) CDC. https://www.cdc.gov/flu/pandemic-resources/1918-pandemic-h1n1.html; (b) *Encyclopaedia Britannica*; (v) Cécile Viboud et al. 2016. Global Mortality Impact of the 1957–1959 Influenza Pandemic; *Journal of Infectious Diseases* 213(5):738–45; (r) R.T. Ravenholt and W.H. Foege. 1982. 1918 influenza, encephalitis lethargica, parkinsonism. *Lancet* 2(8303):860–864; (a) Alfani and Murphy (2017); (t) Paul V. Targonski and Gregory A. Poland. 2017. Influenza. In *International Encyclopedia of Public Health*, 2nd ed., edited by William C. Cockerham. Amsterdam: Academic Press. (p) Stanley G. Payne. 1973. *A History of Spain and Portugal*. Madison, Wisc.: University of Wisconsin Press. (l) James Leasor. 1962. *The Plague and The Fire*. London : George Allen and Unwin. (e) Cindy Ermus. 2015. The Plague of Provence: Early Advances in the Centralization of Crisis Management. *Arcadia* (9). [Arcadia Collection: Disaster Histories.]

centuries—where it is an open question how representative the macroeconomic responses in the case of the Black Death are of large pandemics in general.

Evidence from past pandemics Here we take a macroeconomic view of the consequences of pandemics, and study the average effect of pandemics across a set of major events in Figure 1 dating back to the Black Death, looking at outcomes up to 40 years out. In large scale pandemics, effects will be felt across whole economies, or across wider regions, for two reasons: either because the infection itself is widespread, or because trade and market integration—in capital and/or labor markets—eventually propagates the economic shock across borders. As we explain later, there was a significant amount of regional and even global economic integration in earlier epochs.

To that end, our focus is on European pandemics since macroeconomic data are only broadly available in this region before modern times. We study rates of return on assets using a dataset stretching back to the 14th century, and we focus on 19 major pandemic events where more than 100,000 people died. We also look at more limited evidence on real wages. The events are listed in Figure 1 and, as is clear, the inability of researchers to precisely estimate death tolls in past pandemics hinders our ability to consider event scaling in what follows.

Even for the most famous pandemic event, the Black Death, Herlihy (1997) asserts: "The Black Death of 1348 and 1349, and the recurrent epidemics of the fourteenth and fifteenth centuries, were the most devastating natural disasters ever to strike Europe. We cannot cite exact losses; there are no global figures." Our Figure 1 shows that numerical uncertainty afflicts all death tolls up to, and including, the 20th century. The baseline range of estimates are taken from the newly published study of Cirillo and Taleb (2020), with alternatives from other sources. For some pandemics, the range of estimates varies by a factor of 5 or 10 (e.g., The Italian Plague). Many vary by a factor of 2, such as the "small" plagues, London, Sevilla, Marseille. Estimates for the Black Death itself range from 75 to 200 million. Remarkably, even for as recent an event as the Hong Kong Flu of 1968–69, estimates vary by a factor of 4, from 1 to 4 million. For the Cholera epidemics only a single, round number is given in sources, suggesting a rough guess.

Perhaps this should be no surprise: even now in real time we see authorities, by accident or design, misreporting incorrect case and death counts for COVID-19. Further scaling problems are created across time by the varying size of the local or world population, which Cirillo and Taleb (2020) attempt to control for by scaling up death tolls in past events to a 2020 estimate using the estimated growth of world population over time. These rescaled figures are also shown in Figure 1, but they do not change the ranking materially, and they remain subject to the same wide margins or error. If anything, they tells us that there have been 17 "large pandemics" in our sample and a further 2 "super pandemics": the Black Death and the Spanish Flu. Given this discussion, we identify events purely by a binary indicator, and do not try to scale, although we do consider robustness of results to the inclusion or exclusion of the two super pandemics.

Does COVID-19 belong in this comparison group? To add context, as of November 30, 2020, the global death toll from COVID-19 surpassed 1,468,000 according to the COVID-19 Dashboard at Johns Hopkins University (`https://coronavirus.jhu.edu/`). As Figure 1 shows, that already makes COVID-19 the second most devastating event in over a century, and among the Top 15 deadliest pandemics of all time in rescaled global per capita terms. And it is far from over: should global deaths exceed 3.64 million, a sadly not unimaginable possibility as winter is coming and given a near-linear time path so far, it will enter the historical Top 10.

Theory of the natural rate and economic mechanisms after a pandemic Here our main interest is the response of the real natural rate of interest to a pandemic event. Introduced by Wicksell, and central to modern macroeconomic theory and empirics (Wicksell, 1898; Woodford, 2003; Laubach and Williams, 2003), the real natural rate of interest is the level of real returns on safe assets which equilibrates an economy's savings supply and investment demand—while keeping prices stable. This latent equilibrium variable can therefore serve as a useful barometer of medium-term fluctuations in economic dynamism. In stagnant societies, savings are plentiful relative to investment opportunities (relatedly, see, e.g. Summers, 2014, and his revival of the secular stagnation hypothesis). Formally, in the canonical Ramsey (1928) model of neoclassical growth, it is well known that both population slowdown or greater preference to save will each depress the natural rate (Rachel and Smith, 2017).

In the very long run, from century to century, the natural rate may drift slowly for technological, political, or institutional reasons. But over a horizon of around 10–20 years, medium-term deviations will dominate. Economic theory presumptively indicates that pandemics could be felt in transitory downward shocks to the natural rate over such horizons: investment demand is likely to wane, as labor scarcity in the economy suppresses the need for high investment and raises wages. At the same time, savers may react to the shock with increased saving, either behaviorally as precautionary motives mount in bad times (cf. Malmendier and Nagel, 2011; Kozlowski, Veldkamp, and Venkateswaran, 2020), or simply to replace lost wealth used up during the peak of the calamity. Indeed, 2020Q2 data for both the United States and Europe showed a pronounced upward spike in household saving.

2. Data

To study the macroeconomic responses to historic pandemic events, we use data collected over many years by many economic historians collectively, and then pulled together gradually to form a continuous time series measuring economic indicators at annual frequency in cities, regions, and countries from the 14th century to the present.

Historical interest rates from 1314 to 2018 compiled by Schmelzing (2020) are available at the Bank of England's data repository, where further details on data sources are given. The dataset covers France (1387–2018), Germany (1326–2018), Italy (1314–2018), the Netherlands (1400–2018), Spain (1400–1729, 1800–2018), and the U.K. (1314–2018). European real interest rates are constructed by weighting real interest rates on long-term debt by GDP shares (Maddison, 2010).[1] The underlying assets are debt contracts "which are not contracted short-term, which are not paid in-kind, which are not clearly of an involuntary nature, which are not intra-governmental, and which are made to executive political bodies." More limited data for other time series are available for the UK in the same data repository. Data on real wages for Great Britain from 1311 to 2016 come from the real consumption wage series of Clark (2007) extended by Thomas and Dimsdale (2017). Data on real GDP per capita for England from 1311 to 2016 are obtained from the real GDP per capita at market prices series constructed by Thomas and Dimsdale (2017).

[1]The weighting follows Schmelzing (2020), but results are robust to alternative weightings and also hold when we employ country-specific estimation as shown below. Aggregation weights do not sway the results. Moreover, because our focus is on measures of r^*, interpolation of GDP over decades and centuries essentially has no effect due to smoothing.

3. Empirical design

Unlike controlled experimental settings, economies are complex and dynamic. Even a one-off treatment administered at random will be subject to internal propagation dynamics visible on outcomes over many periods. Pandemics, like natural disasters, offer a unique opportunity to study how economies work. They are natural experiments, but at a much larger scale, with microbiology providing the assignment mechanism. Neither wars, nor natural disasters, nor economic conditions appear to predict their occurrence: There are no obvious simultaneously occurring confounders. Of course, once the pandemic strikes, internal transition dynamics are set in motion, with other intervening factors affecting the economy as time goes by. In this scenario, a useful thought experiment is to consider the economy's response had the pandemic not taken place. In an observational setting, the idea is that by taking averages over time and comparing forecasts of outcomes when a pandemic strikes versus when it does not, we sterilize the effect of all possible intervening factors (including subsequent pandemics that strike within the window of interest). This logic will be familiar to readers brought up in the policy evaluation tradition. In ideal experimental conditions and random assignment, average treatment effects can be calculated as a difference in means. The logic that we follow here is similar, but adapted to a time series setting with observational data.

Accordingly, let $P_t \in \{0, 1\}$ indicate whether or not a pandemic occurs at time t. If there were no other controls to worry about, we could denote with y_t^1 those observations in the "treated" subpopulation, and with y_t^0, those in the "control" subpopulation. An estimate of the *average treatment effect*, τ say, would simply be $\hat{\tau} = \overline{y}^1 - \overline{y}^0$, which can also be estimated from the regression $y_t = \alpha + \beta P_t + e_t$ as $\hat{\tau} = \hat{\beta}$.

In macroeconomic time series, one can calculate a similar statistic that accounts for controls using local projections (Jordà, 2005). That statistic also coincides with the notion of the *impulse response* of a dynamic system. The idea is to compare the conditional expectation (or forecast) of the outcome given the information available today when a pandemic strikes, $P_t = 1$, against the forecast absent the pandemic, $P_t = 0$. And just like the our simple example, it can be easily calculated using regression analysis. Jordà (2005) shows the equivalence between impulse responses estimated by local projections with those estimated with vector autoregressions and other time series linear models commonly used in macroeconomics.

Let's start by characterizing the comparison we are interested in, that is

$$\tau(h) = \mathbb{E}(r^*_{t+h} - r^*_{t-1} | P_t = 1 \,;\, \Omega_t) - \mathbb{E}(r^*_{t+h} - r^*_{t-1} | P_t = 0 \,;\, \Omega_t) \;\;;\;\; h = 0, ..., H \,, \tag{1}$$

where $r^*_{t+h} - r^*_t$ refers to the change in the natural rate from the year the pandemic ends to a future time h years later. P_t is a dummy variable that is 1 if there is a pandemic ending in year t, and is 0 otherwise, and Ω_t refers to the information set available at time t.[2]

Following this discussion, we thus estimate $\tau(h)$ using local projections with the set of regressions

$$r^*_{t+h} - r^*_{t-1} = \alpha^h + \beta^h P_t + \sum_{l=1}^{L} \left[\theta^h_l P_{t-l} + \rho^h_l r^*_{t-1-l} \right] + e^h_{t+h} \;\;;\;\; h = 0, ..., H \,, \tag{2}$$

where clearly $\hat{\tau}(h) = \hat{\beta}_h$. We include 10 lags of the dependent variable to soak up any internal propagation dynamics, or dynamics caused by other variables and proxied by serial correlation in the dependent variable, though the estimate $\hat{\beta}_h$ should change little whether we include these controls or not when pandemics occur at random, as we explained earlier.[3] Of course, the more carefully we can explain fluctuations in the left-hand side variable, the more accurate our estimates of β_h will be.

This type of analysis differs in an important respect from common microeconometric analysis. When calculating a forecast about the future, the risk always exists that other

[2]Most pandemics last for more than one year. We adopt as a timing convention the year when they end. The appendix provides robustness checks against alternative definitions. The results are quantitatively and qualitatively very similar.

[3]The appendix shows experiments using 40 lags. Adding more lags allows for potentially overlapping pandemics within the estimation window. However, as shown in Jordà (2005), local projections are robust to lag length, as the robustness exercises reported in the appendix corroborate.

intervening events will happen in the forecast window. How does this affect the interpretation of the estimates? For example, what happens if another pandemic strikes before the current pandemic has run its course? Here it is important to remember that such eventualities are, a priori, just as likely in the control and treated subpopulations given our assumptions—specifically, that pandemics are, essentially, natural experiments. As a result, in infinite samples their effects are averaged out by construction. By design, local projections take such effects into account.

That said, the Appendix contains several experiments designed to sterilize the effects of concurring events from our estimation. One set of experiments excludes the Black Death and the Spanish Flu since both coincided with large scale armed conflict and economic distress. In addition, we also experimented with adding 40 lags of the pandemic indicator to sterilize the effects of overlapping pandemics in the estimation window. Finally, we also included as regressors 40 future values of the pandemic indicator to also net out the effect of pandemics that happen subsequent to the event under consideration. As the Appendix shows, none of these adjustments makes a material difference, as predicted by the theory.

Estimating the natural rate of interest The natural rate of interest, r_t^*, is not directly observable and has to be inferred from the data. Here we rely on the literature (Laubach and Williams 2003; Holston, Laubach and Williams, 2017; and Jordà and Taylor, 2019), and use a simplified state-space representation, given the limits of the available data. Specifically, we think of the natural rate as the latent process underlying movements in the real rate, described by the following state space:

$$r_t = r_t^* + u_t \, , \tag{3}$$
$$r_t^* = r_{t-1}^* + v_t \, .$$

Thus, to allow for maximum flexibility, the natural rate is a state variable that follows a random walk. Such a model is flexible enough to capture any secular trends without the need to specify a model that describes them directly. The observed rate of interest r_t fluctuates around the natural rate r_t^*. The error terms are assumed to be Normal and the model in Equation 3 can be estimated using the Kalman filter and maximum likelihood methods.

4. Results

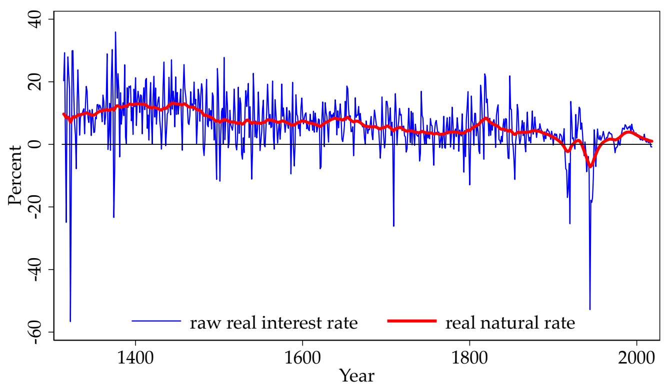
These tools deliver the estimate of the natural rate shown in Figure 2a, based on an aggregate using data from France, Germany, the Netherlands, Italy, Spain and the U.K. We simply call this aggregate "Europe." The figure displays the raw data on interest rates, along with our estimate of the natural rate of interest. Our estimates of the natural rate show the now well-documented secular trend decline over the centuries, from about 10% in medieval times, to 5% at the start of the industrial revolution, and nowadays hovering near 0%. It is easy to see that our estimate of the natural rate goes a long way towards addressing the considerable annual volatility seen in the raw data. Beyond measurement error, that noise also reflects wild fluctuations in harvests, armed conflict, and other events to which pre-industrial societies were exposed to a much greater degree than they are today. With industrialization and modern finance, those fluctuations diminished considerably, as the figure shows.

Figure 2b contains our main result, and displays $\hat{\tau}(h)$, the response of the natural rate to a pandemic, 1 to 40 years into the future. Pandemics have effects that last for decades. Following a pandemic, the natural rate of interest declines for years thereafter, reaching its nadir about 20 years later, with the natural rate about 150 bps lower had the pandemic not taken place. Four decades later, the natural rate is still about 100 bps below the initial level. However, it is no longer statistically different from zero.

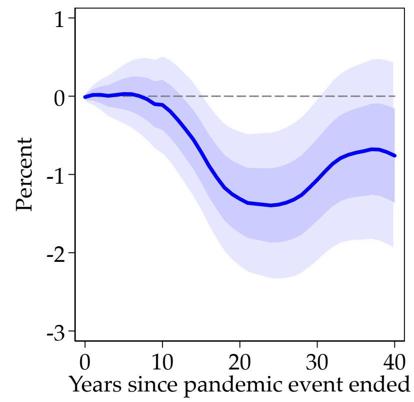
These results are staggering and speak of the disproportionate effects on the labor force relative to land (and later capital) that pandemics had throughout the centuries. It is well known that after major recessions associated with financial crises, history shows that real

Figure 2: *The European real natural rate and response after pandemics*

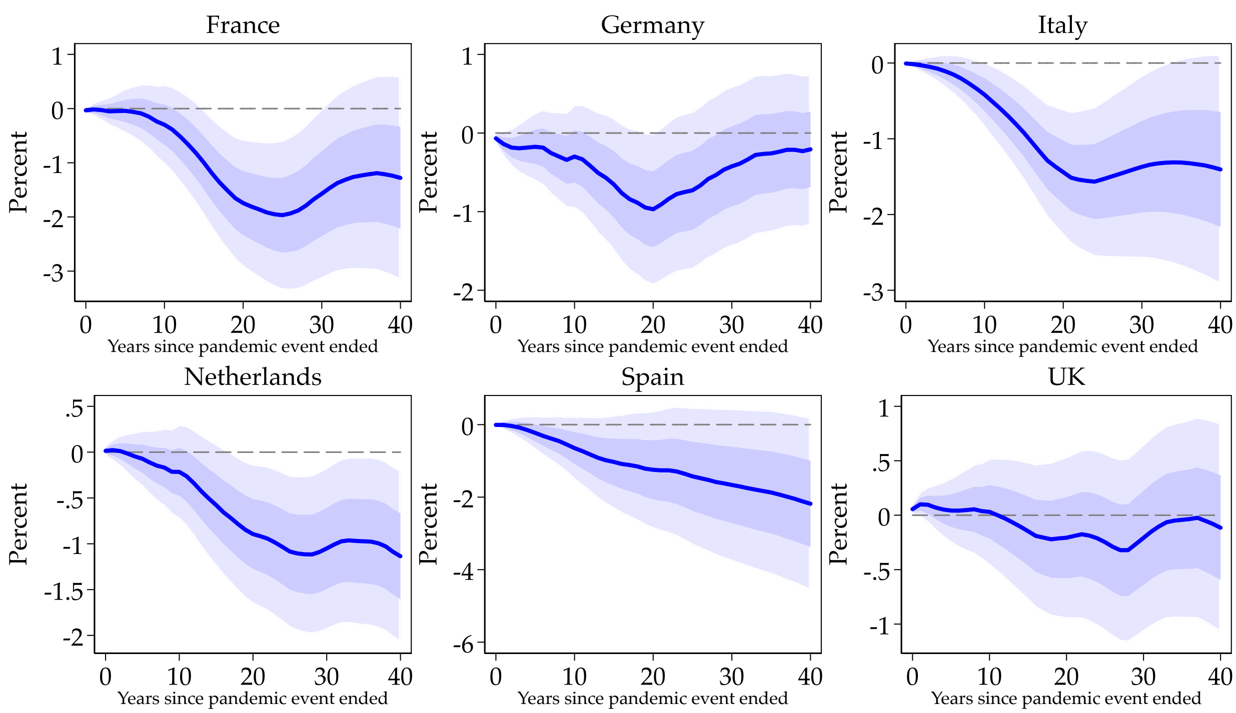
(a) *European real natural rate of interest, 1315–2018*



(b) *Response after pandemics*



(c) *Country-specific response after pandemics*



Notes: Raw interest data from Schmelzing (2020). The real rate is based on the model in Equation 3. Response calculated using Equation 2. Shaded areas are 1 and 2 s.e. bands around response estimates. See text.

safe rates can be depressed for 5 to 10 years (Jordà, Schularick, and Taylor, 2013), but the responses here display even more pronounced persistence.

Of course, because r_t^* is generated by Equation 3, it is a smoother version of r_t. This has two visible effects. First, the response of r_t^* is less immediate than if we had used r_t directly. But this is just as the theory would predict. Changes in population growth rates, long-run productivity and hence the potential rate of growth of the economy do not change overnight. These are slow moving variables and our estimates capture exactly this feature. Going the other way, the effects of the pandemic take longer to be undone for much the same reason.

However, did all countries in the Europe experience pandemics in the same manner shown? Is our choice of aggregation a problem? To answer that question, we turn to Figure 2c where we present similar responses of the natural rate for each of the component economies: France, Germany, Italy, the Netherlands, Spain, and the U.K.

The heterogeneity of the responses turns out to be informative. At one end we have countries like France, Italy, and Spain where the effects of pandemics are much larger (3%–4% for France, Italy and Spain) in contrast to the Anglo-Saxon bloc of the Germany, the Netherlands and the U.K., with far more modest effects on the natural rate.

This heterogeneity reflects, among other explanations, the timing of the pandemics across countries, the relative exposure of each country to the pandemic, the relative size of the working population, how industrialized one economy was relative to another, and even state capacity to respond to the pandemic (though health and public health capabilities beyond simple quarantine were limited in pre-modern times). These are fruitful questions for historians to explore, but without quantitative data it is hard to say anything here using our empirical approach. Without further historical time series to control for and evaluate these modulating influences, we can only say that within the historical range observed, none of these potentially mitigating or amplifying forces was anything like sufficient to materially change the average trajectory seen in one country versus another, as the figure shows.

5. Pandemics versus wars

A natural concern about the validity of these results might be omitted variables, specifically the historical occurrence of other macro-salient events that could persistently disturb real interest rates. One obvious example is war, since the privations of wartime conditions could make diseases more likely. For example, a plague, possibly the first recorded influenza outbreak, occurred among the Athenians during the Peloponnesian War (Thucydides, 2.47–54). However, the correlation of war and disease outbreaks is far from being one.

On the other hand, for the economic indicator of interest in this study, the bias could easily go the other way. Sovereign bond markets were to a large degree an innovation whose origin was military necessity, and the fiscal state had perhaps its most important role as an instrument of war (Brewer, 1990). Yet here the burden of raising large sums via debt finance could just as easily imply higher real interest rates via conventional crowding out arguments, or via risk-premium (e.g., default) channels, or simply due to capital scarcity created by wartime physical capital destruction (a feature absent in pandemics).

To address this concern here we control for wars, by using an indicator variable War_t which is set equal to one in any year in which war-time deaths in Europe exceed 20,000. We obtain the war-time military personnel casualties, beginning only in 1495, from Schmelzing (2020) dataset who draws on the data in Table 4.1 of Levy (1983).[4,5]

We then estimate an augmented local projection to include controls for war. Specifically, we estimate

$$\begin{aligned} r^*_{t+h} - r^*_{t-1} = \alpha^h + \beta^h P_t + \gamma^h War_t \\ + \sum_{l=1}^{L} \left[\theta^h_l P_{t-l} + \phi^h_l War_{t-l} + \rho^h_l r^*_{t-1-l} \right] + e^h_{t+h} \;\; ; \;\; h = 0, ..., H \, , \end{aligned} \tag{4}$$

[4]Total number of battle deaths are divided by duration of the battle (in years) to obtain an annual series of battle deaths. Since battles lasted more than a year, sometimes more than a decade, we think 20,000 deaths per year is comparable to the pandemic death toll threshold of 100,000 we employ.

[5]Readers interested in the debate on severity of pre–19th century epidemics may refer to Alfani and Murphy (2017), Roosen and Curtis (2018), and Biraben (1975), among others.

where we include also the lagged values of this indicator as controls, where the coefficients γ^h are the impulse response of the real interest to a war event in year 0.[6]

Figure 3a and Figure 3b show the result of this exercise, with war controls excluded in the left column, and added in the right column for the shorter sample where war data are available. Our main finding is robust. The dynamic response of the real natural rate to pandemics is as before, and slightly amplified: lower for 30–40 years and in a statistically significant way. But as we anticipated, the effect of war goes the other way: wars tend to leave real interest rates elevated for 30–40 years and in an economically (and statistically) significant way, as also shown in panel (a) of Table 1.

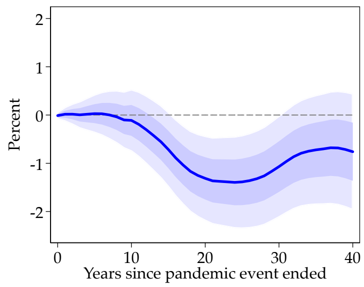
Real wages By defining pandemics as events with 100,000 or more deaths, we have thus far identified episodes with large contractions in the labor force and, hence, in the ratio of labor to capital. We see this as one explanation for the response of the real natural rate of interest. If so, we should see a countervailing response in real wages, and this provides another consistency check. To explore whether this is indeed the case, we use a similar local projection estimator in Figure 3c, where instead of the real natural rate, we use real wages in Great Britain as the response variable and in the control set.

The response of real wages is in the opposite direction to the response of the real natural rate, with its effects being felt over decades. Figure 3c shows that real wages grow gradually so that forty years out the cumulative deviation in the real wage is about +10%. Contrast the response of wages after wars in Figure 3d, which remain pretty much unchanged. A formal test of the differences is provided in panel (b) of Table 1. These results match the predictions of the neoclassical model, and accord with historical narratives: in general pandemics, as with the Black Death, have induced labor scarcity in the European economy, and pushed real wages up. In equilibrium, this went hand in hand with lower returns to capital.

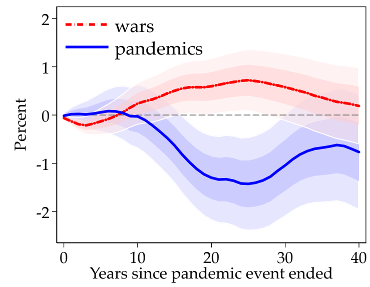
[6] Wars often last for several years. We focus on war-year pairs with 20,000 casualties or more. Hence, to eliminate the overlapping effect of large casualties felt over consecutive years, we add up to 10 lags of our dummy variable as a right-hand side variable.

Figure 3: *Response after pandemics and wars*

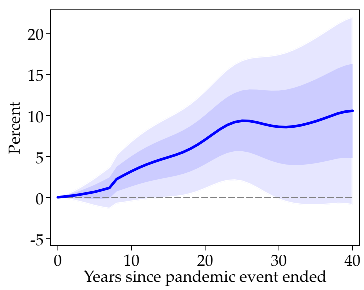
(a) *Response of European real natural rate*
Sample: 1310–2018



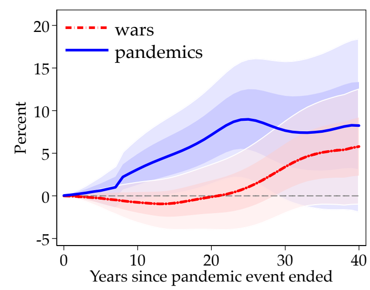
(b) *Response of European real natural rate*
Sample: 1495–2018



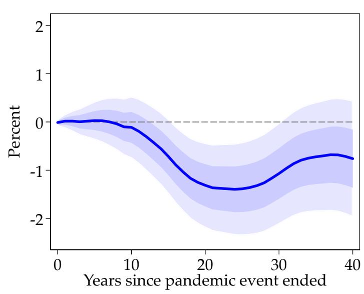
(c) *Response of real wages in Great Britain*
Sample: 1310–2018



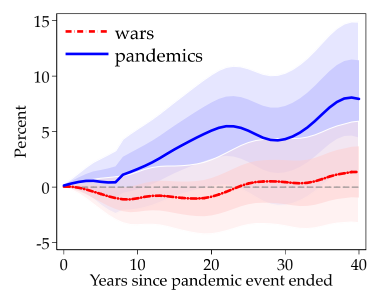
(d) *Response of real wages in Great Britain*
Sample: 1495–2018



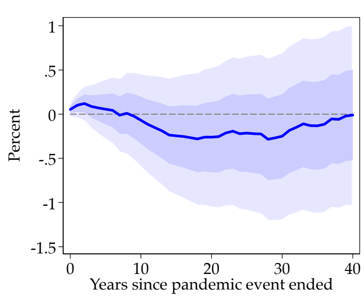
(e) *Response of real GDP per capita in England*
Sample: 1310–2018



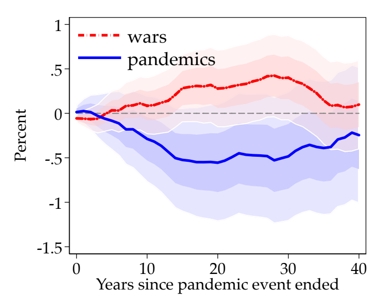
(f) *Response of real GDP per capita in England*
Sample: 1495–2018



(g) *Response of $r - g$ in England*
Sample: 1310–2018



(h) *Response of $r - g$ in England*
Sample: 1495–2018



Notes: Response calculated using Equation 4. Final two panels use trends estimated for real wages in Great Britain and real GDP per capita in the UK. Details on trend estimation is provided in Appendix A. Shaded areas are 1 and 2 s.e. bands around response estimates. See text.

Table 1: *Responses after pandemics and wars*

Horizon year	$h = 0$	$h = 10$	$h = 20$	$h = 30$	$h = 40$
(a) Responses of European real natural rate at years 0 to 40 (change from year −1 baseline)					
Pandemics	-0.02	-0.03	-1.30***	-1.04**	-0.77
	(0.04)	(0.33)	(0.44)	(0.53)	(0.60)
Wars	-0.06**	0.24	0.60**	0.58*	0.19
	(0.02)	(0.22)	(0.29)	(0.35)	(0.40)
H_0 : Pandemics = Wars, p-value	0.29	0.51	0.00	0.01	0.19
Observations	524				
(b) Responses of real wages in Great Britain at years 0 to 40 (change from year −1 baseline)					
Pandemics	0.04	3.12*	7.15**	7.66*	8.25
	(0.05)	(1.81)	(2.90)	(4.07)	(5.11)
Wars	-0.01	-0.76	-0.12	3.40	5.79*
	(0.03)	(1.21)	(1.93)	(2.72)	(3.40)
H_0 : Pandemics = Wars, p-value	0.41	0.08	0.04	0.39	0.69
Observations	522				
(c) Responses of real GDP per capita in England at years 0 to 40 (change from year −1 baseline)					
Pandemics	0.14*	1.63	5.09**	4.32	7.95**
	(0.09)	(1.82)	(2.53)	(2.99)	(3.48)
Wars	0.05	-1.01	-0.87	0.45	1.37
	(0.06)	(1.21)	(1.69)	(1.99)	(2.31)
H_0 : Pandemics = Wars, p-value	0.36	0.23	0.05	0.29	0.12
Observations	522				
(d) Responses of $r - g$ in England at years 0 to 40 (change from year −1 baseline)					
Pandemics	0.01	-0.29	-0.56*	-0.48	-0.25
	(0.04)	(0.24)	(0.33)	(0.36)	(0.38)
Wars	-0.06**	0.09	0.28	0.40*	0.10
	(0.03)	(0.16)	(0.22)	(0.24)	(0.25)
H_0 : Pandemics = Wars, p-value	0.14	0.20	0.04	0.04	0.46
Observations	522				

Notes: Standard errors in parentheses. See text.

Real GDP per capita Finally, we display the response of real GDP per capita in Figure 3e and Figure 3f for England, the only economy for which we have long-run data. Here again, the contrast between wars and pandemics is self-evident, with formal tests provided in panel (c) of Table 1. The destruction of capital (and loss of lives) during wars, has a noticeable negative effect on labor productivity that is absent in pandemics, where in fact, labor productivity increases.

Debt sustainability and $r - g$ While the short-run fallout from pandemics looks similar to other economic disasters—large and sudden declines in economic activity—the medium- to long-run economic consequences are staggeringly different, as we have shown. And these differences matter for policymakers. In any such abrupt downturn, the textbook response is to either borrow to smooth the shock, or to pursue aggressive stimulative fiscal policy to counter the shock. Both will likely result in a rapid buildup of public debt. However, the sustainability of such debt depends crucially on the type of economic disaster confronted.

In order to illustrate this point we turn to Figure 3g and Figure 3h. These show the response of the real natural rate minus the growth rate of real GDP per capita, call it $r - g$, using natural rate data only for the U.K. and for real GDP per capita growth rates for England, as above. If this difference becomes more negative, it becomes easier to sustain higher levels of debt. Conversely, when this difference becomes more positive, debt sustainability becomes harder. Once again, we see that pandemics and wars have very different consequences in this respect as well.

We see that in the aftermath of pandemics, $r - g$ becomes slightly negative, by about 50 basis points around the 20 year mark, before essentially returning back to equilibrium. In contrast, wars result in a boost of about 100 basis points, peaking around the 30 year mark. Panel (d) in Table 1 evaluates the differences between these two paths every decade. Though somewhat noisy, the difference between the two paths is statistically significant (at the 10% level) on impact, and in the years surrounding the second to third decades, as also seen in panel (d) of Table 1, and of course a test that both paths are equal to one another jointly is rejected at a 5% confidence level. Regardless, what is important here is the difference in the economic magnitudes and these are sizable.

6. Robustness

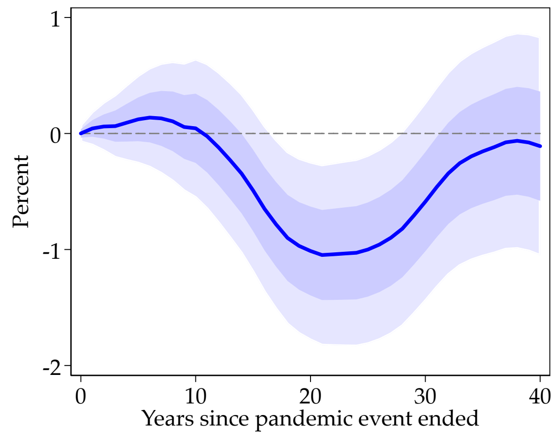
Robustness to possible major trend breaks Schmelzing (2020) proposes three historical dates at which the trend for the real interest rate could have changed. These are the "post–Bullion famine" period following the end of the global monetary contraction (1494), the "North-Weingast" institutional revolution that led to emergence of credible public debt mechanisms in Britain (1694), and the "post-Napoleonic" founding of the modern international state system (1820). Although the state-space model from Equation 3 is sufficiently flexible, to confirm that our results are not affected by such shifts, we add controls for time trends starting at these historical dates. Figure 4a plots the newly estimated response of the European real natural rate following a pandemic event. As the figure shows, our baseline result is largely unchanged. The trough is similar and happens at about the same time.

Robustness when excluding small and localized pandemics The plagues of London, Sevilla, and Marseille in Figure 1 were largely localized, not affecting the wider European region very much. Some other plagues had relatively small death totals. One may therefore be concerned that these relatively smaller events could attenuate the response of the aggregate European real natural rate. Figure 4b recalculates the response of the real rate when omitting the six smallest pandemics in Figure 1. The peak response in the real natural rate is slightly larger when estimated with the remaining "global" pandemics, as one would expect. These smaller pandemics exerted a smaller influence on the real rate.

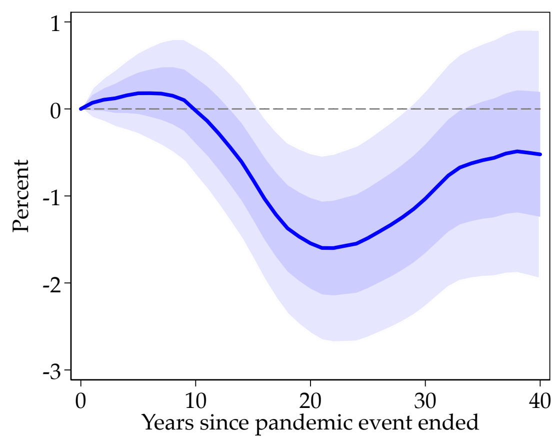
Robustness when excluding the Black Death and the Spanish Flu Finally, in Figure 4 we consider removing from the sample the two largest events in history, the Black Death and the Spanish Flu. The resulting response is presented in Figure 4c and separately in

Figure 4: *Response of real natural rate: robustness*

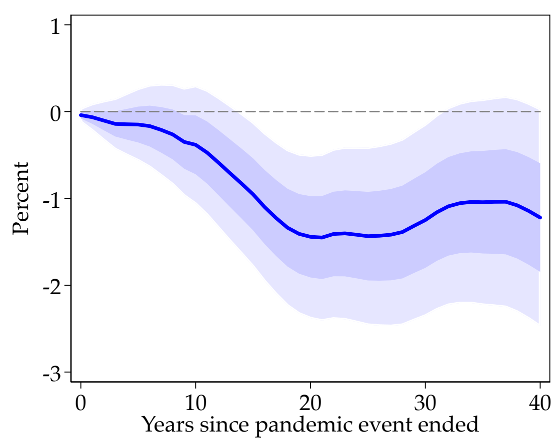
(a) *Allowing for trend breaks*



(b) *Excluding the six smallest pandemics*



(c) *Excluding the Black Death and the Spanish Flu*



Notes: Response calculated using Equation 2. Shaded areas are 1 and 2 s.e. bands around response estimates. See text.

Figure A2a and Figure A2b. The Black Death stands out for having decimated the European population, thus having an outsize weight in explaining the decline of the natural rate. Although the Spanish Flu was not quite as deadly as the Black Death, it came on the heels of WW1 and was followed ten years later by the Great Depression. Naturally one might worry that the decline in the natural interest rate was due to the Great Depression and not the pandemic. However, as Figure 4c shows, removing these two influential events from the sample does not affect our main result materially.

Response of stock prices Though not a robustness check per se, we conclude this section by briefly commenting on the response of stock prices to pandemics. The available data are usually too short in span to capture most of the pandemics in the sample. However, data for the U.K. start in 1709, providing a reasonable sample for analysis. Figure A5b in the Appendix shows stock market declines reaching about 0.20 log points after 40 years in the counterfactual (i.e., returns lower by 0.5% per year). Though the decline is estimated imprecisely this can be seen as auxiliary evidence of low real rates of return across asset classes.

7. Conclusions

Summing up our findings, the great historical pandemics of the last millennium have typically been associated with subsequent low returns to assets, as far as the limited data allow us to conclude. These responses are huge. Smaller responses are found in real wages, but still statistically significant, and consistent with the baseline neoclassical model. Measured by deviations in a benchmark economic statistic, the real natural rate of interest, these responses indicate that pandemics are followed by sustained periods—over multiple decades—with depressed investment opportunities, possibly due to excess capital per unit of surviving labor, and/or heightened desires to save, possibly due to an increase in precautionary saving or a rebuilding of depleted wealth.

Should we expect declines in the real natural rate as large as 1.5%–2% following the COVID-19 pandemic? There may be at least three factors that will likely attenuate the decline of the natural rate predicted by our analysis. First, the death toll of COVID-19 relative to the total population will hopefully be be smaller than in the worst pandemics of the past, although we cannot know for sure at this point. Second, COVID-19 primarily affects the elderly and other high-risk individuals, who are usually out of the labor force and tend to save relatively more than the young. The demographic channels that we discussed earlier are not quite at play in the same manner today, although the more recent waves of infections are now affecting younger individuals. Third, aggressive counter-pandemic fiscal expansion measures will boost public debt further and this might put some upward pressure on the natural rate. That said, with other forces in play acting to lower interest rates, this expansion of public debt should be easier to sustain in the long-run.

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A. Appendix: Estimation of trends

We use the following state-space system, presented in Equation 3, to estimate trends for log real wages and log real GDP per capita. Let y_t be the variable whose potential trend y_t^* is to be estimated, where g_t is the growth rate of the potential trend.

$$
\begin{aligned}
\hat{y}_t &= y_t - y_t^* \,, && \text{(gap)} \\
y_t^* &= y_{t-1}^* + g_{t-1} + u_{y,t}^* \,, && \text{(potential)} \\
g_t &= g_{t-1} + u_{g,t} \,. && \text{(potential growth)}
\end{aligned} \tag{5}
$$

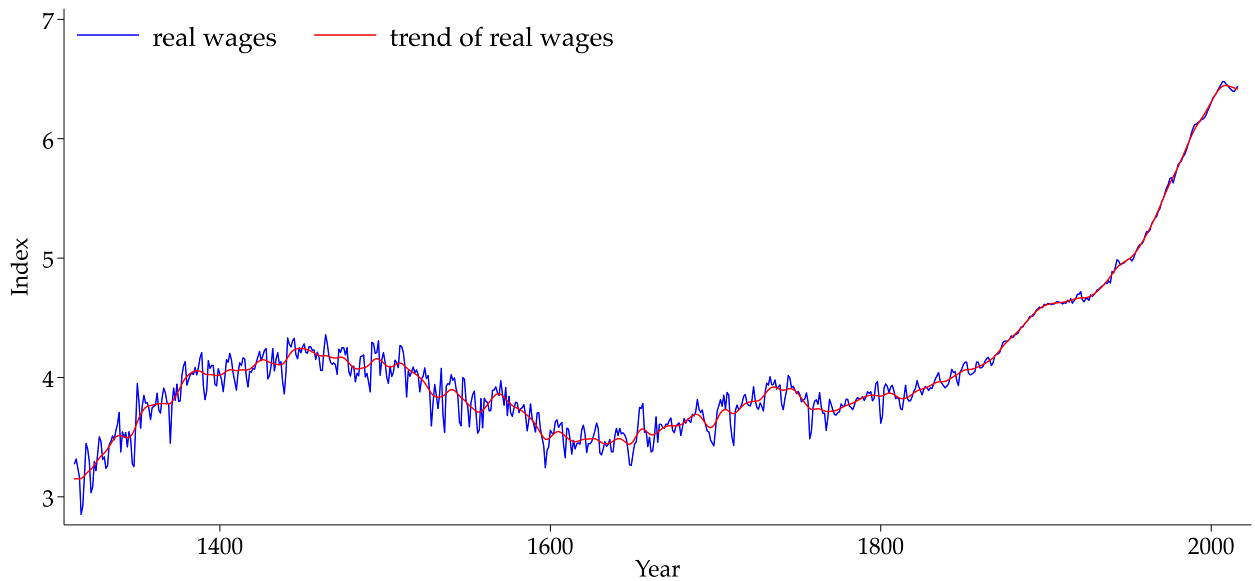
Figure A1 shows the estimated trend for real wages and real GDP per capita.

B. Appendix: Additional Robustness Checks

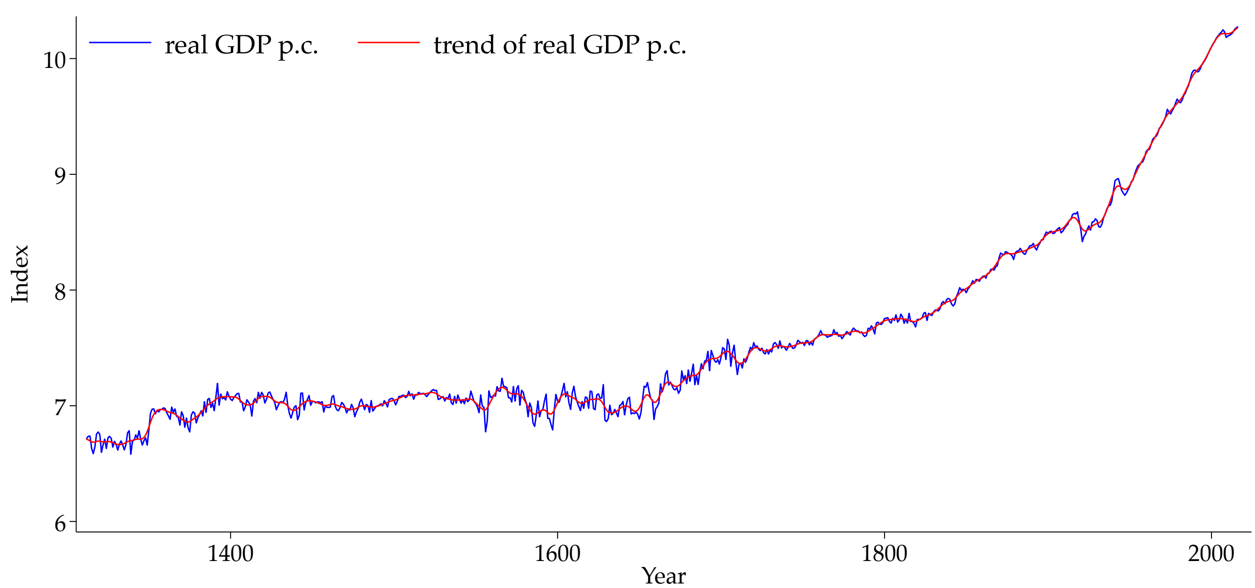
Additional robustness exercises are shown in Figures A2 through A5 below.

Figure A1: *Estimated trends of log real wages and log real GDP per capita in the UK*

(a) *Real wages in Great Britain*

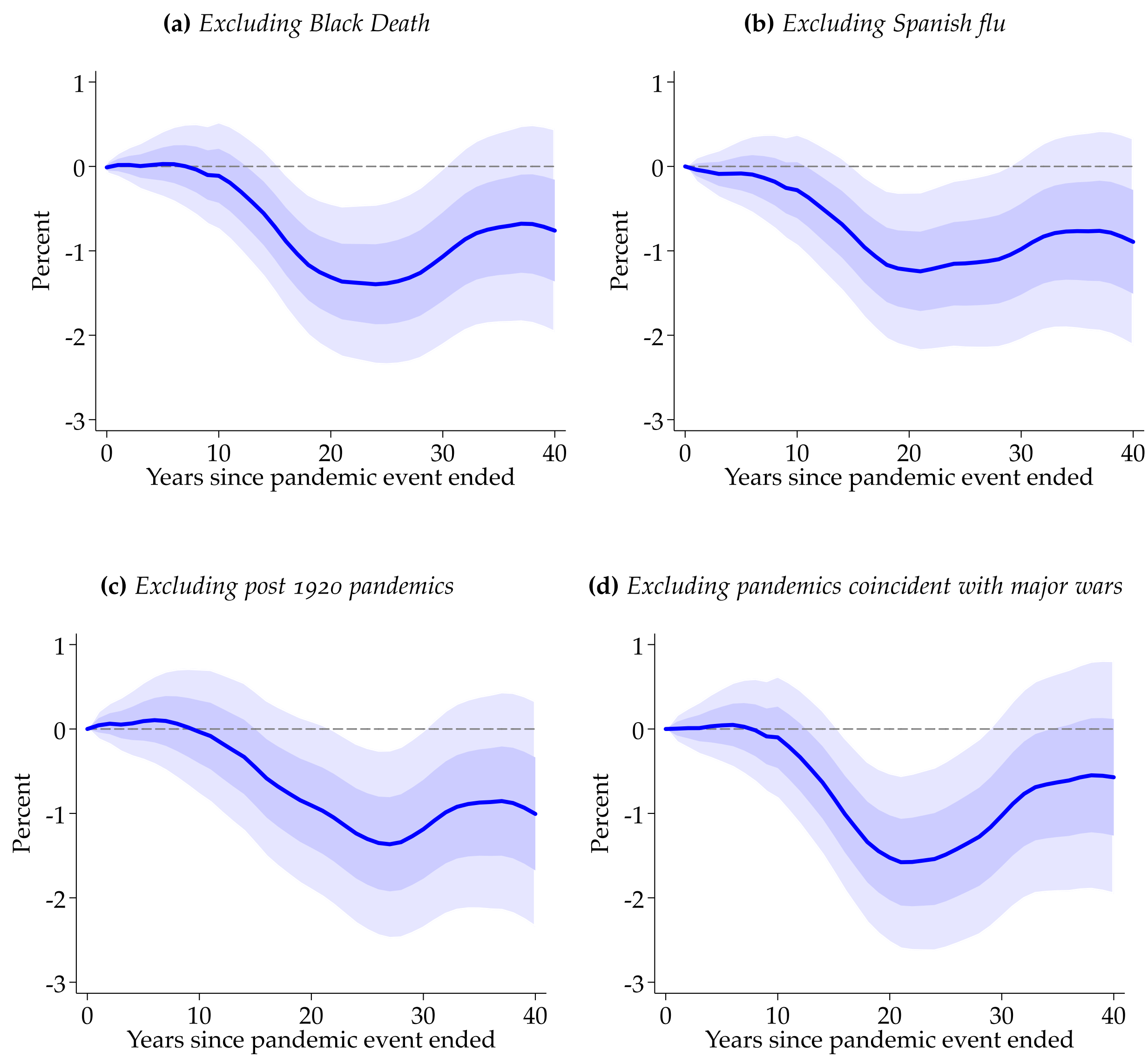


(b) *Real GDP per capita in England*



Notes: Raw data for real wages in Great Britain and real GDP per capita of England are obtained from Thomas and Dimsdale (2017). Trends estimated with a state-space system following Laubach and Williams (2003), presented in Equation 5. Real GDP per capita series is based on market prices and is quoted in "£mn, chained volume measure, 2013 prices." Real wages are in the form of an index where 1900 real wages are normalized to 100. In the graphs presented, these series are plotted on log-scale.

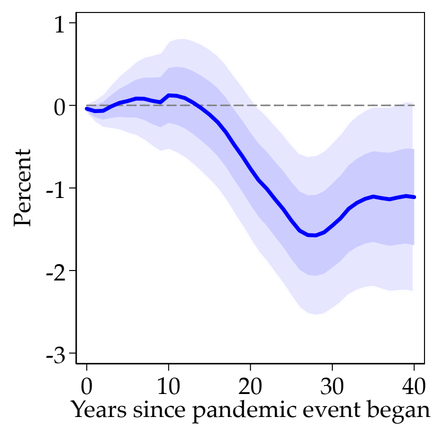
Figure A2: *Response of real natural rate: robustness to different modifications as noted*



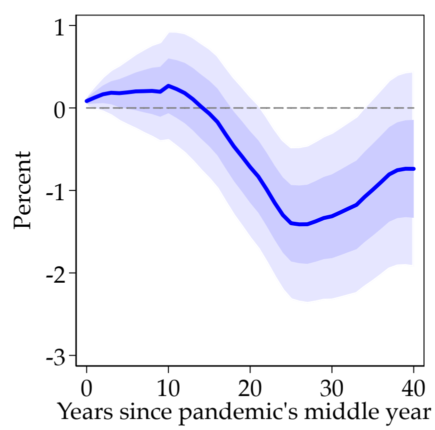
Notes: Response calculated using Equation 2. Shaded areas are 1 and 2 s.e. bands around response estimates. See text.

Figure A3: *Response of real natural rate: robustness to pandemic dating*

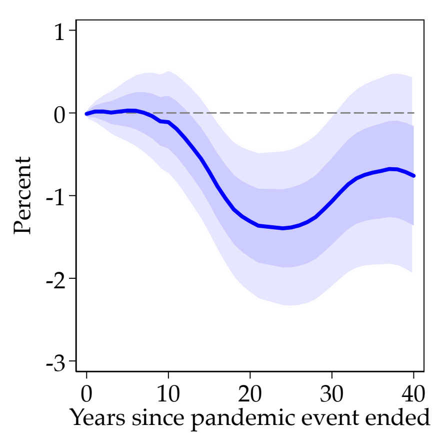
(a) *Start year*



(b) *Middle year*



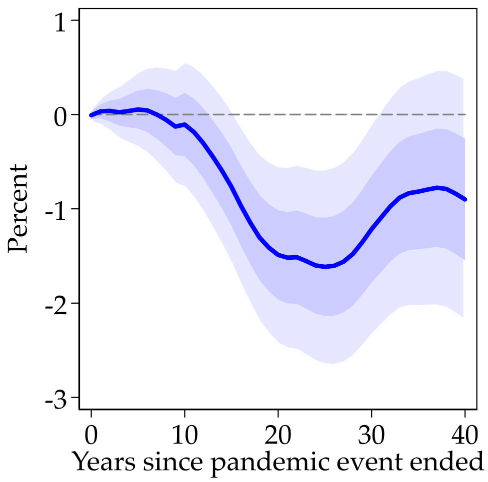
(c) *Baseline: End year*



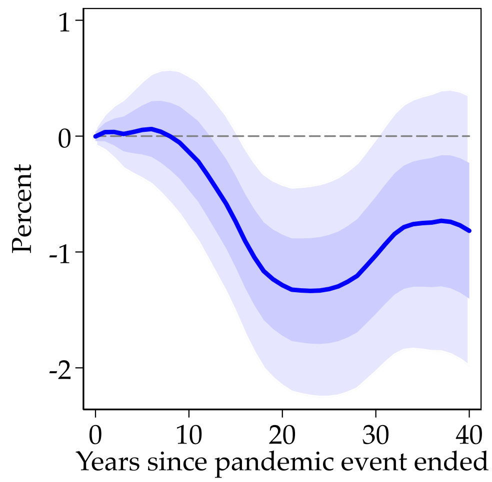
Notes: Response calculated using Equation 2. Shaded areas are 1 and 2 s.e. bands around response estimates. See text.

Figure A4: *Response of real natural rate: robustness to additional lagged and forward controls*

(a) *40 lags*



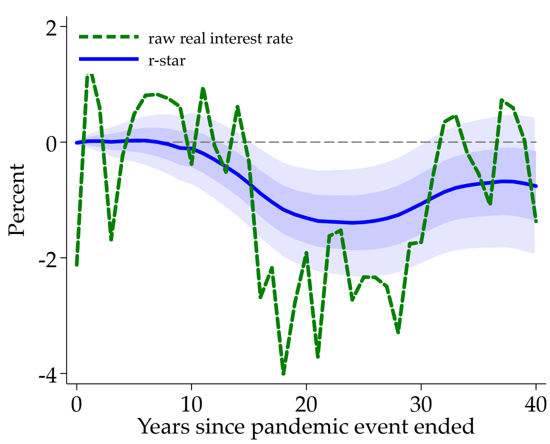
(b) *10 lags and 40 forwards*



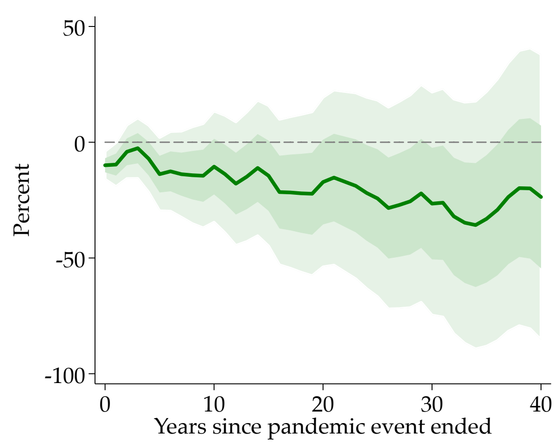
Notes: Response calculated using Equation 2. Shaded areas are 1 and 2 s.e. bands around response estimates. See text.

Figure A5: *Response of European real rate (%) and UK stock price index (*$\log \times 100$*)*

(a) *Response of Real rate and R-star in Europe*

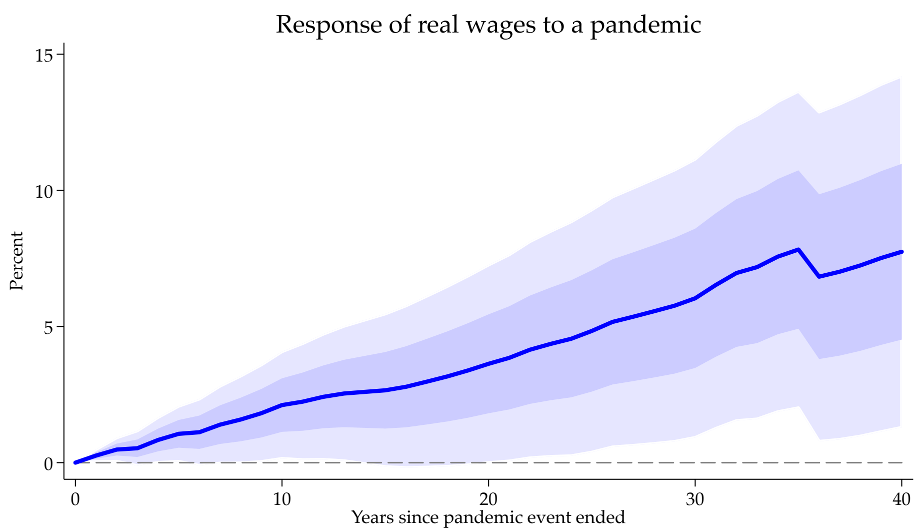


(b) *Response of UK stock price index*



Notes: Response calculated using Equation 2. Shaded areas are 1 and 2 s.e. bands around response estimates. See text.

Figure A6: *Response of pooled European real wages (25 year moving average)*



Notes: Response calculated using Equation 2. Shaded areas are 1 and 2 s.e. bands around response estimates. See text.