# When did Germany cease to be Malthusian?

## The evolution of the preventive and positive checks, 1730–1870*

(this version, September 2014)

Georg Fertig

Universität Halle

Institut für Geschichte

Hoher Weg 4

06120 Halle (Saale)

georg.fertig@geschichte.uni-halle.de

Ulrich Pfister**

Westfälische Wilhelms-Universität Münster

Historisches Seminar

Domplatz 20–22

D-48143 Münster

pfister@uni-muenster.de

* Contribution to First European Conference on Historical Demography, Alghero, September 2014.

** Corresponding author.

## Abstract

This study employs new datasets of vital events and real wages for Germany to produce estimates of the Malthusian checks for the time period 1730–1870. Both VAR and separate estimation of distributed lag regression coefficients are used. The results obtained with these two methods suggest that the positive and the preventive checks were both present up to c. 1800. The preventive check was much weaker than the positive check, suggesting that eighteenth century Germany was characterized by a high-pressure Malthusian situation. C. 1800–1815 the response of vital rates to fluctuations of the real wage declined. After the Napoleonic Wars, the positive check had disappeared for most periods, and its strength was much reduced in those periods when it was still significant. The preventive check, by contrast, was of similar magnitude as before 1800, at least if unobserved health effects of negative real wage shocks are controlled for. The weakening of the positive check in the aftermath of the Napoleonic Wars is explained with an increase of grain market integration, which eased the shocks originating from regional harvest failures, and a strong rise of labour productivity around 1820. A side-result of the study is a proposal for an appropriate implementation of an unrestricted recursive VAR to Malthusian analysis and a discussion of the implications of our VAR analysis for richer formulations of a Malthusian system.

JEL codes: C32, I15, J11, J13, N33

Keywords: Historical demography; economic development; vector autoregression

# 1. Introduction

Establishing the time point when demographic variables, mortality in particular, became independent from short-term fluctuations of material welfare has the potential to produce insights into the long-term evolution of material welfare and growth in an economy. In the specific case of Germany, the development of income per capita in the decades preceding national unification in 1871 still remains surrounded by extreme uncertainty and is difficult to determine (Burhop and Wolff 2005: 634–5). Demographic evidence can thus contribute to identify the pattern and timing of the transition to modern growth.

Whether or not an economy should be termed Malthusian depends from two criteria: First, Malthusian economies are often considered as technologically static; with the absence of technological progress the downward sloping marginal product of labour results in a negative relationship between population size and material welfare. Conversely, the break-up of a negative relationship between population size and a measure of material welfare such as the real wage can be interpreted as a transition to a non-Malthusian economy.

Second, a Malthusian situation is often associated with the existence of a preventive and a positive check. The first refers to a positive response of fertility to a (positive) real wage shock, the second to a negative relationship between mortality and the real wage. The disappearance of these checks, particularly the release from hunger as a break on population growth (the positive check), indicates that a Malthusian regime has been overcome.

In this study we focus on the second criterion. We employ a novel dataset of national birth and death rates for Germany and apply two methods, separate estimation of distributed lag regression coefficients and vector autoregression, to assess the evolution of the preventive and positive checks over the period 1730–1870. We establish that the preventive check persisted over the whole period, whereas the positive check became very weak after the first two decades of the nineteenth century. These results can be combined with those of a separate study (Pfister et al. 2012), which shows that around c. 1820 the demand for labour began to increase sufficiently to counteract the negative effect of rapid population growth on material welfare. We conclude, therefore, that Germany became non-Malthusian during the early nineteenth century, most probably during the latter half of the 1810s.

This finding is remarkable given that the transition to a non-Malthusian regime occurred several decades before the onset of rapid industrialization from the 1840s. Drawing on other recent and ongoing research into nineteenth-century German economic history we consider market integration as the prime candidate to explain Germany's transition to a non-Malthusian state in the late 1810s. Market integration was promoted by the formation of large territorial states in 1815, institutional reforms that abolished internal tariffs, and programmes of infrastructure construction. Market integration facilitated inter-regional balancing of surpluses and deficit in foodstuffs, and it contributed to Smithian growth.

The study is organized as followed: We start with the exposition of a simple Malthusian model to derive the criteria to distinguish between a Malthusian and a non-Malthusian regime, and discuss different research strategies to implement a Malthusian model for historical populations. We then describe our data and their time series properties. In the two central sections we carry out separate estimations of the two Malthusian checks using distributed lags regression and vector autoregression, respectively. The conclusion summarizes the findings and puts them into a larger perspective.

## 2. A Malthusian system and its empirical implementation

A standard Malthusian model is specified by the following equations (cf. Lee and Anderson 2002: 197, 205–207; Møller and Sharp 2008: 3):

$$w_t = \alpha_t - \beta p_t + \varepsilon_{wt} \tag{1}$$

$$b_t = c_0 + \sum_{i=0}^{l} \gamma_i w_{t-i} + \varepsilon_{bt} \tag{2}$$

$$d_t = c_1 + \sum_{i=0}^{l} \delta_i w_{t-i} + \varepsilon_{dt} \tag{3}$$

$$p_t = p_{t-1} + b_{t-1} - d_{t-1} \tag{4}$$

where $w_t$ denotes the natural logarithm of the real wage, $p_t$ the natural logarithm of population size, $b_t$ the crude birth rate and $d_t$ the crude death rate, all in year *t*. $\alpha_t$, $\beta$, $\gamma$ and $\delta$ constitute partly time-varying structural parameters of the system, $\varepsilon_{wt}$, $\varepsilon_{bt}$ and $\varepsilon_{dt}$ denote random shocks operating, respectively, on *w*, *b* and *d*, whereas finally $c_0$ and $c_1$ are constants; *l* is the number of lags taken into consideration to assess the effect of *w* on *b* and *d*.

Equations (2) and (3) represent the preventive and the positive checks, respectively. Since Malthusian theory expects a positive effect of the real wage on the birth rate and a negative effect on the death rate, the presence of the two checks is given when the conditions $\Sigma\gamma > 0$ and $\Sigma\delta < 0$ hold. Equation (1) represents the demand for labour, in which $\alpha_t$ traces the evolution of the level of labour productivity over time, whereas $\beta$ measures the marginal return to labour, assuming that that the labour-force participation ratio and the annual labour input per worker remains constant over time. Under these assumptions equation (1) also captures the Malthusian feedback of population on the real wage; $\beta$ indicates how strongly the real wage is depressed by population growth at a given level of technology. Equation (4), finally, simply closes the system by describing how the vital rates affect population size. Note that no net migration is assumed; this restriction can of course be relaxed.

An economy can be considered as Malthusian when technology is static (i. e., when $\alpha_t$ remains constant over time) and when both checks show the expected sign and deviate substantially from zero. Within a Malthusian regime several possible configurations of the central structural parameters exist. Malthus himself essentially argued for England around the turn of the nineteenth century that the preventive check was largely non-existent ($\Sigma\gamma=0$) and that the whole burden of demographic adjustment to fluctuations of the real wage rested on the positive check ($\Sigma\delta < 0$). In general, a situation in which $|\Sigma\delta| > |\Sigma\gamma|$ prevails can be termed a high-pressure Malthusian system. The reverse situation, in which adjustment to real wage fluctuations operates mainly through the birth rate ($|\Sigma\gamma| > |\Sigma\delta|$), can be labelled a low-pressure Malthusian system.

An economy becomes non-Malthusian, first, when the level of technology $\alpha_t$ shifts outward over time so that the negative effect of population growth on the real wage through the fall of the marginal product of labour is cancelled out. If this happens, the Malthusian feedback of demographic processes on material welfare is broken. Second, an economy becomes non-Malthusian when the checks vanish. Particularly the disappearance of a relationship between material welfare and mortality, that is, of the positive check, points to the transition to a non-Malthusian regime. This does not imply the non-existence of demographic shocks, but only their exogeneity relative to the relationships contained in the Malthusian model. For instance, the fluctuations of the vital rates might depend on forces unconnected to the real wage in the short run, such as epidemics and wars.

Early implementations of a Malthusian model for historical populations have focused on the two Malthusian checks and have estimated these separately using distributed lag regression (major contributions include Lee 1981; Weir 1984; Galloway 1988, 1994; applications to Germany also include Fertig 1999; Guinnane and Ogilvie 2008). While these studies still constitute a benchmark that helps to put in perspective new research, they suffer from two weaknesses. First, they are handicapped by data limitations. Work for other countries and regions than England in particular mostly relied on grain prices as a proxy for the real wage. Whereas food prices certainly constitute a major component of the cost of living particularly during subsistence crises they certainly cannot capture forces driving real income through labour demand, such as technological progress and market integration. Second, separate estimation of Malthusian checks cannot take account of possible interactions between the processes underlying both the preventive and the positive check. Lee and Anderson (2002: 198–9; also Lee 1981; Galloway 1988) for instance argue that unobserved variations in health exerted an influence on both mortality and fertility.

More recent research has thus not only drawn on new, expanded and improved data sets but has also assimilated methods developed in modern macroeconomics in attempting to specify an econometric setup for the estimation of a Malthusian system as whole, rather than considering individual relationships in isolation. The first approach that has come to be employed in historical demography is vector autogression (VAR). This method estimates the dynamic interactions between the variables constituting a system over a specified number of lags. Typical applications in modern macroeconomics include the analysis of the mechanisms and the temporal pattern with which an external shock, such as a spike in international commodity prices, works itself through an economy. Estimation is usually performed with monthly or quarterly data, and the time horizon refers to usually less than ten lags and a system's dynamic over three to five years (for an example, see Stock and Watson 2001).

An advantage of VAR is its non-theoretical approach; it simply takes into consideration all possible linear interactions between the variables of a system over a pre-defined period of time. This implies that it usually consumes a high number of degrees of freedom, however. Most time series in historical demography are of annual frequency, which limits the number of degrees of freedom that can be absorbed by an estimation model. At the same time, Malthusian feedback through equations (4) and (1) above is a long-run process that takes place over the time span of a whole generation. This implies lag numbers of 20 and more, which leads to a VAR with a very high number of degrees of freedom even for a very parsimonious system of three or four variables. In practice, therefore, in historical demography the VAR technique has been essentially confined to the estimation of the preventive and the positive checks, that is, demographic adjustment to a real wage shock, rather than a Malthusian system as a whole (Eckstein et al. 1985; Nicolini 2007; Crafts and Mills 2009: 77–81).

Another challenge of applying VAR to historical demographic data consists in the existence of several varieties of VAR and that results can vary depending on the setup chosen (for a non-formal presentation, see Stock and Watson 2001). We shall argue below in section 5 that earlier studies have been moderately successful in implementing a VAR that is compatible with prior knowledge on historical populations. Hence, one contribution of this study is the specification of a VAR setup that can be considered as appropriate for the historical study of Malthusian checks. Finally, one should be aware of the fact the subject of this study is structured by a theory, namely Malthusian theory as set out above, and that considerable knowledge on the interrelationships among the variables involved has accumulated over the past decades. VAR is by definition non-theoretical, and the capacity of a non-theoretical research tool to test a theory is necessarily limited. The contribution of VAR to the historical study of Malthusian relationships thus consists mainly in providing an exploratory tool: By taking into account all possible dynamical relationships among the variables of a system it allows to check whether an important structural relationship exists in the data that is missed out or wrongly specified by existing theory, which is by definition reductionist. As it turns out later in this study, our VAR analysis suggests that the real wage-fertility relationship set out in equation (2) above does not appropriately specify the preventive check and that future research should endeavour to expand both the model and the data used for testing it in order to adequately describe the operation of the preventive check.

A second strategy to estimate a Malthusian system in its entirety is to develop a structural time series model and to estimate it using a Kalman filter as proposed by Lee and Anderson (2002; for a replication, see Crafts and Mills 2009: 81–91). The great strength of this approach is that allows explicit modelling and estimation of the trajectory of the demand for labour $\alpha_t$ in equation (1). However, to obtain a stable solution for the coefficients and $\alpha_t$ vectors the model specification should be parsimonious. The specification of the two Malthusian checks has in fact been carried out in a more restricted way than in some earlier separate estimates. The method's complexity also limits the possibility to trace the evolution of the strengths of the checks over time.

On this background we believe that with the methods currently available it is not feasible to investigate the evolution of a Malthusian system in its entirety over time and we resolved to carry out separate studies of short-term adjustment of demographic variables to real wage shocks and of Malthusian feedback, respectively. Hence, the present study focuses on the two Malthusian checks, whereas the analysis of the labour demand relationship is carried out in a separate paper (Pfister et al. 2012). As we shall discuss at greater length in the conclusion, the two studies lead to strikingly similar conclusions.

## 3. Data sources and data series properties

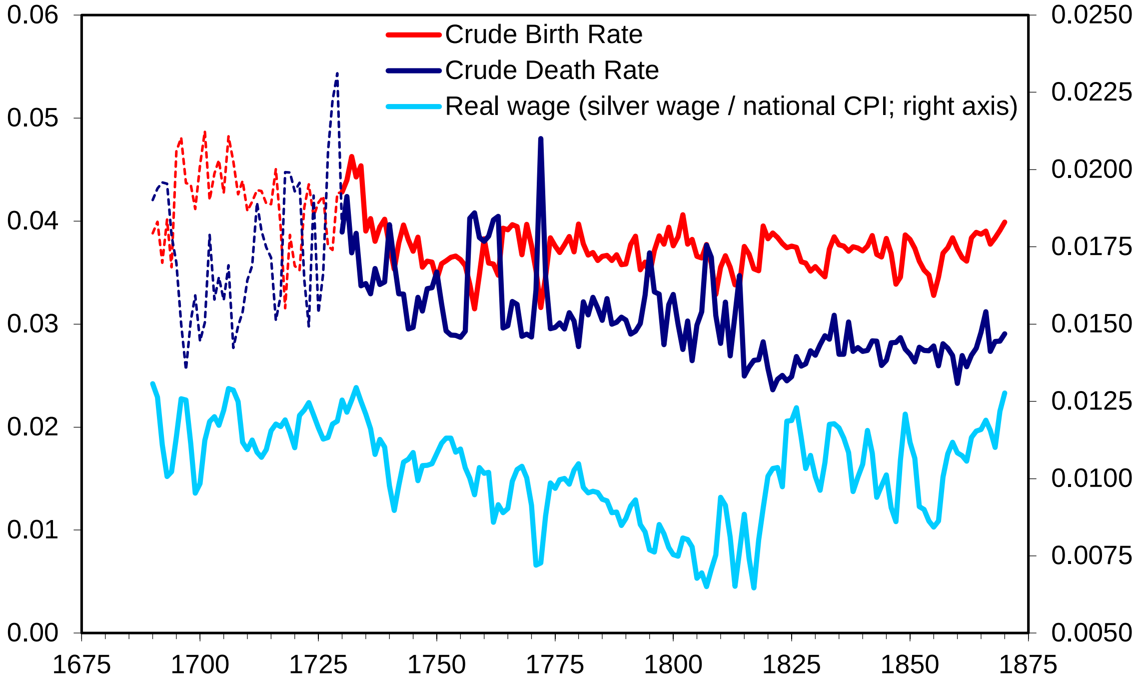
Our investigation into Malthusian checks in Germany draws on a novel dataset of annual series of the crude birth rate, the crude death rate and the real wage for the period 1730–1870. The real wage relates to the day wage of unskilled building labourers in ten to sixteen towns and is taken from Pfister (2010). Calculation of vital rates from c. 1815 rests on statistical information from individual German states and compiled by Kraus (1980); in addition, we integrate corrections and amendments suggested by Gehrmann (2000). For the period between the 1730s and the 1810s we rely largely on proto-statistical records of individual German territories. The bulk of the information is provided by Gehrmann's (2000) study on northern Germany, which is complemented with material from other regions. Around 1790 coverage of vital events is about 30 per cent of estimated national totals. As one moves back in time, this rate shrinks as sources established by state authorities peter out, and correspondingly, the third main category of sources that we use, namely, parish registers, gains in importance (some 140 parishes in the present version of the series). This is particularly true for the time before 1740, when information for whole territories provided by state archives is very rare. We have constructed annual time series of population, births and deaths back to 1690, but before 1730 our estimates of population growth and natural increase derived from vital events are grossly inconsistent. For this reason we use our series only from 1730 (for details, see Pfister and Fertig 2010: 4–30).

We consider this dataset as provisional in three major respects. First, while estimates of population growth and natural increase calculated from births and deaths are by and large consistent from 1730 and coverage is high compared to similar aggregative population reconstructions for other countries, information for the eighteenth century is heavily biased towards Protestant regions. If Catholics and Protestants differed with respect to their demographic behaviour this bias may distort results. Second, due to changing boundaries and dislocation resulting from the Napoleonic Wars, our database is again more restricted and unstable during the period c. early 1800s to 1815. Due to inflationary war finance the quality of the consumer price index used in calculating the real wage is also somewhat dubious. Third, we believe there is much potential in expanding the dataset back in time on the basis of church records and partial censuses covering specific segments of the population, which were established by town, church and state authorities. In sum, whereas we consider our present findings concerning the weakening of the positive check to be fairly robust we expect that future improvement and expansion of the data will add to our knowledge relative to the emergence and stability of the Malthusian checks in the long run.

Our investigation differs from the earlier analysis by Galloway (1988: 300) on Prussia in 1750–1870, first, by a broader regional coverage and an improvement of data quality, particularly thanks to the work since done by Gehrmann (2000). This notably includes the difficult period c. 1805–1815. Second, Galloway proxies the income variable with the average of the grain price in three towns. We employ a cost of living index with much broader coverage and introduce wages explicitly. Finally, Galloway does not break down his series into sub-periods; consequently, he does not make a statement on the evolution of the Malthusian checks in the period of observation.

Figure 1 charts the course of the data series over the one-and-a-half centuries prior to national unification. Visual inspection suggests the following main patterns: First, after strong fluctuations in the first third of the eighteenth century, which may be related to poor data coverage and quality, the crude birth rate remained largely stable from the mid-1730s and fluctuated in a narrow band between 30 and 40 per thousand. Second, mortality crises related to low real wages, which point to harvest failures leading to subsistence crises, are visible in 1740, weakly in 1750, in the early 1770s and in 1795. The mortality spikes in 1740 and 1771 correspond to well-known pan-European subsistence crises (Post 1985). The crises of 1795 and possibly 1750 may have been more of a regional character.

*Figure 1: Crude birth rate, crude death rate and real wage, 1690/1730–1870*




*Sources*: Crude birth and death rates: Pfister and Fertig (2010); real wage: Pfister (2014). The dimension of the real wage (right axis) is the fraction of a consumer basket consumed annually by an adult town dweller that can be purchased with the summer day wage of an unskilled building labourer.

Third, material welfare and mortality were strongly affected by wars. The Seven Years' War (1756–1763) went together with a high death rate over its entire duration, and the time of the Napoleonic Wars saw at least two episodes with deaths in excess of births (1807/08 and 1814). With the exception of 1762, these mortality spikes do not correspond to short-term throughs in the real wage, that is, they appear as exogenous to a Malthusian system as described above. Probably these mortality crises followed from the easy spread of epidemics as a consequence of sanitary problems during sieges and war-related mobility, as well as from difficulties in food distribution resulting from the breakdown of markets (cf. Stier and von Hippel 1996).

Forth, no episode of excess mortality occurred anymore after the end of the Napoleonic Wars. In particular, the outbreak of the Tambora volcano in 1815, which led to a series of harvest failures all over the world (Post 1977) and which can be well traced in the German real wage (through in 1817), produced only a small blip in the death rate. Nevertheless, it should be stressed that particularly poor regions with many land labourers, whose employment opportunities were negatively correlated with harvest outcomes, continued to experience subsistence crises until 1855 (Bass 1991).

Fifth, the disappearance of mortality crises after 1815 went together with a strong upward shift of the real wage in the years around 1820. Changes in mortality patterns thus went hand in hand with a marked improvement of material welfare. During the remaining decades until national unification the real wage remained largely on the same level, albeit with strong fluctuations particularly during the 1840s and 1850s. This is remarkable given the strong population growth during this period (0.8 per cent annually in 1820–1870). Between the mid-1730s and the Napoleonic Wars, by contrast, the real wage seems to have followed a falling trend. A separate analysis of the labour demand function in equation (1) above in fact shows that labour demand declined between the 1740s and the early 1800s, experienced a strong positive shock around 1820 and shifted outward at a moderate rate, but fairly continuously thereafter (Pfister et al. 2012). Whatever our findings relative to the strength of the Malthusian checks will be, the long decline of the real wage during the eighteenth century suggests that Malthusian checks, even if they existed, were ineffective in adjusting population to a decline in labour demand. By contrast, the long-term stability of the real wage in the half-century after c. 1820 implies that the outward shift of labour demand was sufficient to compensate for the Malthusian feedback, that is, the negative effect of population growth on material welfare.

The remainder of this section discusses the steps taken to prepare the data series for later analysis. Following standard practice in earlier work on Malthusian checks we remove the short-run effect of fertility on mortality (which is due to a high proportion of infant deaths) by isolating the non-infant death rate. The non-infant death rate ($CDRn0_t$) is estimated following Weir (1984, p. 37):

$$CDRn0_t = d_t - (imr \cdot (s \cdot b_t + (1-s) \cdot b_{t-1})) \quad (5)$$

where *imr* is the infant mortality rate, *s* the separation factor; i.e. the proportion of infant deaths occurring within the calendar year of birth, and $b_t$ and $d_t$ the crude birth and death rates as in equations (2–4) above, all in year *t*. The separation factor has been assumed to be 0.74, again following a suggestion by Weir. The infant mortality rate is assumed to be 0.170.[1]

*Table 1: Unit root and stationarity tests of vital rates and the real wage*

| | Augmented DF | KPSS |
|---|---|---|
| *a. 1730–1799* | | |
| Crude birth rate | -3.52* | 0.379⁺ |
| Crude birth rate, de-trended | -5.96** | 0.067 |
| Crude death rate (CDR), net of m0 | -6.15** | 0.384 |
| CDR, net of m0, de-trended | -6.92** | 0.062 |
| ln (real wage) | -2.27 | 2.172** |
| ln (real wage), de-trended | -5.24** | 0.032 |
| *b. 1800–1870* | | |
| Crude birth rate | -4.22** | 0.126 |
| Crude birth rate, de-trended | -7.32** | 0.051 |
| Crude death rate, net of m0 | -4.60** | 0.291 |
| CDR, net of m0, de-trended | -7.23** | 0.053 |
| ln (real wage) | -1.60 | 1.741** |
| ln (real wage), de-trended | -4.79** | 0.020 |

*Sources:* Own calculation based sources for Figure 1.
*Notes:* De-trended values were calculated using a Hodrick-Prescott filter with $\lambda=100$. Options used in the unit root tests (all include an intercept in the test equation estimate): Augmented Dickey-Fuller test (null hypothesis: series has a unit root): Lag length selection with AIC information criterion, maximum lags=7; Kwiatkowski-Phillips-Schmidt-Shin test (null hypothesis: series is stationary): short truncation lag parameter. Levels of statistical significance: $^{+}$ $p < 0.1$, * $p < 0.05$, ** $p < 0.01$.

Given the Malthusian model in equations (1) to (4) above we would like to analyse the levels of the crude birth rate and the crude death rate net of infant mortality, and the natural log of the real wage. The methods used in the later sections of this study presuppose that the underlying data series are stationary. Therefore, we have conducted unit root and stationary tests reported separately for two sub-periods in Table 1. The salient result is that the real wage is clearly non-stationary in both sub-periods, and no clear conclusion is possible for the birth rate in 1730–1799. On the background of these findings we have de-trended all series using a Hodrick-Prescott (HP) filter with $\lambda=100$. The remaining short-term fluctuations are all clearly stationary so that they can be analysed with the methods used below. However, the result also implies that a simple VAR cannot be used to estimate a complete Malthusian system at least in the German case, because the interaction between

1 This is a rather arbitrary assumption taken from Fertig (1999: 246); cf. Gehrmann and Roycroft (1990: 83). We shall use time varying and/or regional estimates based on Inverse Projection in later versions of this investigation. Our current estimates of IMR from Inverse Projection do not fit well with what is known on IMR from family reconstitution studies. Empirical data could also be generated from family reconstitution studies to calculate time varying or regional separation factors.

the Malthusian checks and the feedback through the population-wage relationships involves a relationship in the long run, which is filtered out by de-trending.

## 4. Separate estimation of Malthusian checks using distributed lags regression

The goal of the following section is to develop and a present a theory-driven empirical model of the positive and preventive checks in Germany, 1730 to 1870. In other words, we want to find parsimonious specifications, which take into account what is known based on abstract modelling and previous research. We will later compare these results with the results of a VAR analysis, which is non-theoretical.

The distributed lags approach determines the presence and strength of a Malthusian check by regressing the crude birth or death rate, respectively, on the real wage and on lags both of itself and the real wage. Following Weir (1984), we employ a specification that includes two lags of the dependent variable and three lags of the real wage:

$$n_t^* = \sum_{k=0}^{3} \beta_k w_{t-k}^* + \gamma_1 n_{t-1}^* + \gamma_2 n_{t-2}^* + \varepsilon_t \quad (5)$$

with $n_t$ denoting the birth rate or non-infant mortality rate at time $t$, $w$ the natural log of the real wage and $k$ lags 0 to 3; $\beta_k$, $\gamma_1$ and $\gamma_2$ are estimation parameters and $\varepsilon_t$ represents a randomly distributed error term. Stars (*) symbolize filtering of the variables using a HP filter as explained above. We estimate the regression coefficients with OLS.

Figure 3 displays estimates of the Malthusian checks on the basis of equation (5) for moving time windows of 31 years. The graphs refer to the cumulative elasticity of the birth rate (preventive check) and the non-infant death rate (positive check, inversed sign) on the real wage.

Our setup differs in several important ways from earlier studies: First, we use real wages rather than grain prices as an indicator of income. This has consequences for the size of the resulting coefficients. Grain price fluctuations were typically large in preindustrial societies, with strong reactions particularly of mortality. Real wage fluctuations were somewhat smaller, since only a part of the real income was determined by grain prices. A rather minor real wage movement could have the same (large) impact as a large grain price movement. Consequently, regression coefficients obtained on the basis of the real wage are higher than estimates based on the grain price as proxy for income.

Second, following Lee and Anderson (2002) and others, we use natural logs of the real wage, but not of the vital rates. This means that the resulting coefficients (or their sums) cannot be directly interpreted as elasticities of the vital rates in reaction to a change in prices, as in other specifications (e.g. Weir 1984), but rather as the elasticity of the population, through fertility or mortality, in reaction to a change in wages (e.g. a preventive check of .020 tells us that a 100 per cent change, a doubling, of the real wage would raise the population size by a fifth through increased fertility)

Third, we use a HP filter (with a Lambda of 100), not the division by a moving average, as a means of detrending. This does not have additional consequences for the interpretation of our results.

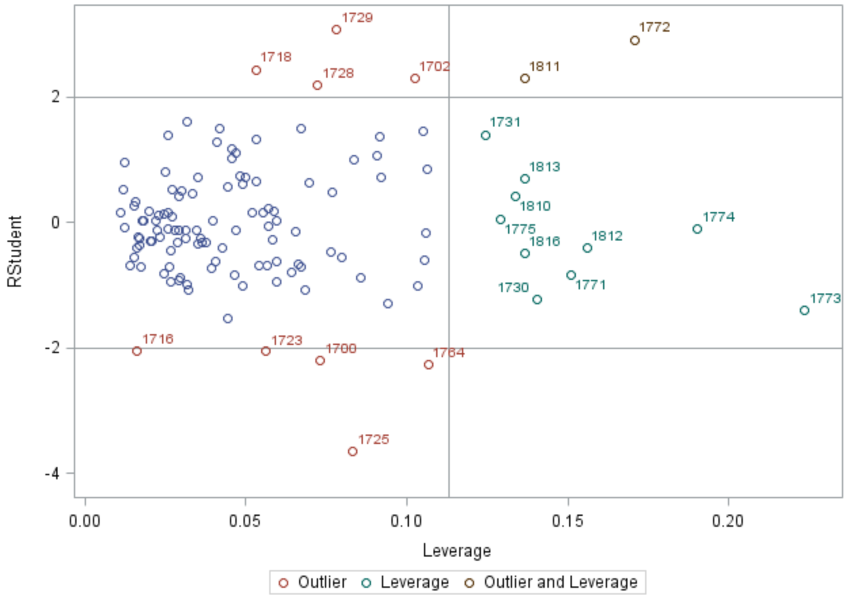
Fourth, we do not use an autocorrelation correction method for second-order autoregressive disturbances such as Yule-Walker or Cochrane-Orcutt (the latter was used by Galloway 1988), but rather include two lags of the dependent variable, following Weir (1984). Consequences should be minor.

Fifth, whereas Galloway (1988) tests the joint significance of the lag sums (sums of regression coefficients) using a chi-square test, we use an F test for testing the null hypothesis that the lag sums are zero.

Sixth, a major difference between our analysis and earlier work concerns the determination of the number of lags being included in the computation of cumulated elasticities. Earlier studies have always used a fixed number of lags (Galloway 1988 used lags 0 to 4, Weir 1984 used lags 0 to 3), and have typically calculated regressions for a time span of about 50 or over 100 years. We calculate regressions for moving time windows of 31 years, starting in 1730 to 1760, continuing with 1731 to 1761, and so on. We determine the optimal lag length for each time window by summing up the coefficients, and we report (and test) the sum where we found it to be at its maximum for the preventive check or at its minimum for the positive check, respectively. For instance, a real wage shock affected mortality only during the current and the following year during most of the eighteenth century, but had a longer impact over the current year and three lags at the end of our period. Thus, our lag sums for the positive check tell us how many people died earlier when incomes broke down; they do not answer the less relevant question how many people died earlier net of other people who survived in later years due to a post-shock rebound (and vice versa for fertility).

In a previous version of this paper (Pfister/Fertig 2010), we presented regression results for the preventive and positive checks using moving time windows as explained above (with a slightly different data set and model specification); and one of the results was that the positive check for the $18^{th}$ century was strong, but very unstable; also it seemed that during the Napoleonic period results were insignificant perhaps because of limited data quality. A reason for this can be that there were atypical years both in the sense of outliers and in the sense that some observations (years) exert a very strong influence (leverage) on the estimation of the regression parameters. Figure 2 presents both the Rstudent statistics (studentised residuals) for outliers, and the hat matrix diagonal H statistics as proposed by Belsley, Kuh, and Welsch (1980) for the detection of years with a very high leverage, based on a regression analysis for the positive check for all years 1690 to 1816. Following Belsley et al., we excluded years with a hat diagonal beyond 2p/n from further regression analysis, where n is the number of observations used to fit the model and p is the number of parameters in the model (in our case: 0.113). Moreover, we excluded years with a Rstudent value above 2.0 or below -2.0. Exclusion was done by setting the (HP filtered) values of mortality, fertility, and real wage for these years to zero (in other words, to the trend component of these variables as calculated for these years).

*Figure 2: Outsider and leverage diagnostics for the positive check, 1690 to 1816*



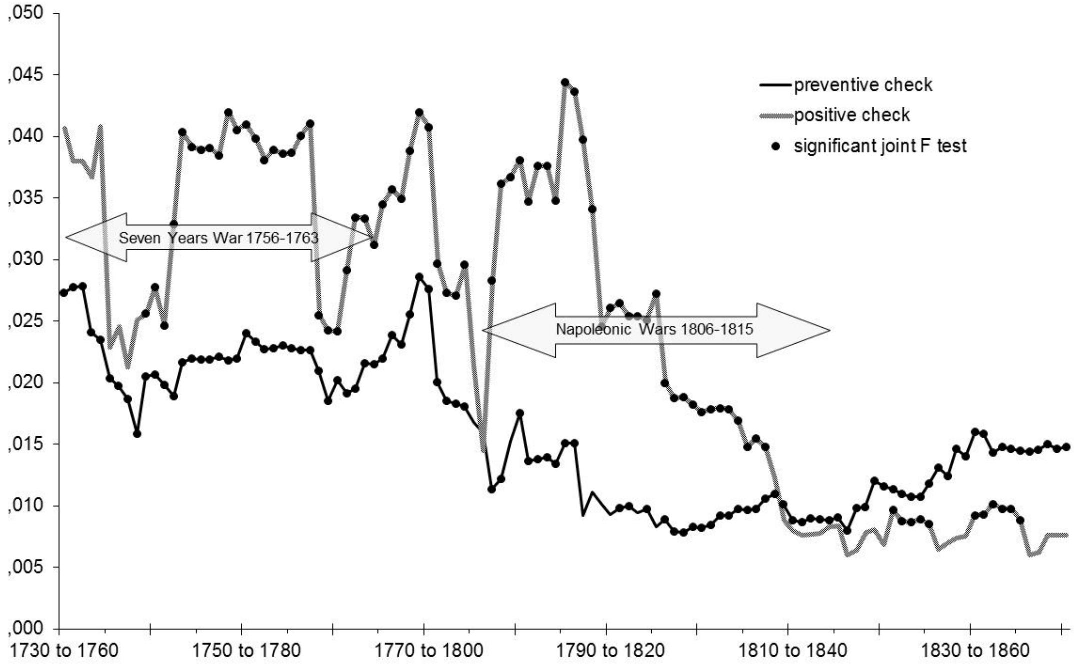

The Napoleonic period indeed scored high on atypical years (1810-1813). Since the preventive check is captured with significant but small coefficients even without the atypical years it seems that data quality is not a major issue for these years; the problem is specific to the way mortality was connected to incomes. Inspection of individual years shows that in some years such as 1772, there were more deaths than predicted in the model. This is hardly surprising since mortality was certainly not only influenced by the movement of incomes, but also by the much more erratic activity of microorganisms. Other years such as 1764 or 1773 show less deaths than expected. Possibly, in 1764, the post-war deflation crisis that struck large parts of Germany and depressed the incomes of agricultural producers artificially makes our real wage indicator look too good. In 1773 as in other years after a large mortality crisis, it is possible that the survivor population consisted of people with relatively strong health, leading to a rebound not captured by the model in more normal periods.

Figure 3 depicts the intensification and reduction of the positive and the preventive checks over time, leaving out the atypical years in the 18$^{th}$ century as explained above. Dots mark regressions that yield significant lag sums (in other words, the sum of the coefficients is jointly significant for the lag where it reaches its maximum). In reading the graph, one should bear in mind that the depicted regression coefficients refer to time periods of 31 years, not time points.

A first conclusion that emerges from Figure 3 relates to the fluctuation of the estimates across adjacent observation periods, which is still considerable for the positive check in the earlier period. This should be read as a warning against making arbitrary decisions about the cutting points between early and later time periods. Including a few data points (such as the Seven Years' War) can change the results massively.

Second, up to c. 1800 the preventive and the positive checks were both present, but the positive check was considerably stronger than the preventive check. This characterizes 18th century Germany as a poor and underdeveloped economy with a high-pressure demographic system, and fits with the low and falling real wages of the same period.

*Figure 3: Cumulated elasticities for the preventive and positive checks, 1730 to 1870*




*Note:* Arrows designate the time windows affected by a specific shock.
*Sources:* Own calculation.

Third, it appears that in the eighteenth century, the preventive and the positive check moved in a parallel or at least not in a complementary fashion, and that both fell off between the 18th and 19th centuries (the preventive check even somewhat earlier). At first sight, this questions the Malthusian intuition that there was a trade-off between positive and preventive checks—that populations had to suffer from stronger positive checks when the preventive check was weak. A possible interpretation for this roughly joint movement of the two checks may be that there were times (of war and climatic shocks in particular), when national real wages and local income fluctuations were closely correlated, and other times when they were more at variance. But market integration was clearly stronger in the 19th century, so that our results might also suggest that the trade-off did not exist.

Fourth, when we move on to the nineteenth century, we see the positive checks (or the impact of hunger crises) almost disappear. However, in the period between 1821 (at the earliest) and 1865 (at the latest), significant positive checks returned, albeit on a low level, possibly reflecting the negative income trends during the 1830s and 1840s. Within the period 1815 to 1870, we found a significant positive check in the distributed lags regression for 11 out of 26 of the 31 years time windows estimated (that is, for the periods 1821 to 1851 until 1825 to 1855, and again 1830 to 1860 until 1835 to 1865, while in the 15 estimates where the time window begins in the years 1815 to 1820, 1826 to 1829, and 1836 to 1840, the positive check was not significant). The preventive check stays in force on a reduced level in a much more consistent way. Thus, the early nineteenth century saw a profound change in the demographic regime, particularly with respect to mortality.

## 5. Vector autoregression

This section uses the data described in section 3 above to perform a vector autoregression (VAR) analysis of the short-run relationships between the vital rates and the real wage. We analyse responses to orthogonal responses, which conform to a recursive VAR. The approach can be described by starting with a reduced form VAR of the form:

$$y_t = A_1 y_{t-1} + \ldots + A_p y_{t-p} + u_t \qquad (6)$$

where $y_t = [y_{1t}, \ldots, y_{Kt}]^T$ is a vector of $K$ endogenous variables with zero mean and a standard deviation of one, $A_{it}$ are $[K \times K]$ matrices of estimation coefficients and $u_t = [u_{1t}, \ldots, u_{Kt}]^T$ is a $K$-dimensional white noise process of random shocks with covariance matrix $\Sigma_u$ operating on the endogenous variables, all at time $t$. $p$ is the number of time lags, which defines the order of a VAR; a VAR(p) has $p$ lags. Standardization of the variable vector $Y_t$ to zero mean and a standard deviation of one is done to simplify the exposition and has no substantive implications.

In the present analysis the $y_t$ vector of endogenous variables consists of three variables, namely, the birth rate $b_t$, the death rate $d_t$ and the real wage $w_t$. A reduced form VAR can be implemented with three equations that regress the three variables on their own lagged values and the lags of the other two variables up to lag $p$. Since no contemporaneous effects in year $t$ are included the system can be validly estimated using OLS. Note that this VAR constitutes only a partial implementation of a Malthusian system because population is omitted. This is done on the grounds that the feedback effect of demographic adjustment to real wage shocks back to material welfare via population is a long-run process that requires too many degrees of freedom to be modelled with a VAR. At the same time, however, the nontheoretical nature of VAR renders it capable to describe the information present in the data in a much richer way than an approach that is guided by a Malthusian model such as the one of section 1 alone. This is because in addition to equation (5) above it includes all possible linear relationships between the variables involved over the entire lag period.

The most common way to interpret the results of a VAR is by considering impulse responses. Impulse responses are derived by calculating the effect of a unity shock on a variable in time t on itself and all other variables during subsequent time periods when it works itself through the system. Thus, for variable $k$ an error or innovation of $u_{kt}=1$ is assumed and the values of all variables resulting from this shock in $t+1$, $t+2$ etc. are calculated using the estimated parameters $A$. If the underlying data series are stationary, the effects of the shock should die out after a finite number of time periods. The concept of the impulse response is wider than the concept of elasticity employed in earlier sections because it embodies possible interactions between the variables in the system, which the calculation of an elasticity does not (cf. Eckstein et al. 1985: 299–300 with respect to applications to historical demographic data). By contrast, the sum of the estimation coefficients for variable *k* in the equation for variable *l* divided by the mean of *l* yields only the partial elasticity of *l* on *k* net of interactions of these two variables with all other variables in the system.

In order to consider only orthogonal effects of shocks, that is, those independent from each other, it has become common to compute so-called Choleski impulse responses. They are derived through a Cholesky factorization of the covariance matrix $\Sigma_u$ of the reduced form VAR. Its effects are that the residuals of the individual regressions in (6) become uncorrelated and that contemporaneous effects become visible in impulse response analysis. In addition, it can be shown that Cholesky factorization of the error terms covariance matrix $\Sigma_u$ of the reduced form VAR actually implies the expansion of the reduced form VAR into a recursive VAR (Lütkepohl 2007: 46–7, 58–9; for an intuitive formulation, see Stock and Watson 2001: 103).

To orthogonalize impulses the covariance matrix is decomposed such that $\Sigma_u = \mathrm{W}\Sigma_\varepsilon \mathrm{W}'$, where $\Sigma_\varepsilon$ is a diagonal matrix with positive elements and $W$ a lower diagonal matrix with unit diagonal. Multiplying equation (6) with $\mathrm{A} = W^{-1}$ yields:

$$\mathrm{A}\, y_t = A_1^* y_{t-1} + \ldots + A_p^* y_{t-p} + \varepsilon_t \qquad (7)$$

where $A_i^* = \mathrm{A}\, A_i$ (with $A_i$ as in equation 6 above) and $\varepsilon_t$ has the diagonal covariance matrix

$$\Sigma_\varepsilon = E(\varepsilon_t \varepsilon_t') = \mathrm{A}E(u_t u_t')\mathrm{A}' = \mathrm{A}\Sigma_u \mathrm{A}'$$

Adding $(I_K - \mathrm{A})y_t$ to both sides of (7) gives:

$$y_t = A_0^* y_t + A_1^* y_{t-1} + \ldots + A_p^* y_{t-p} + \varepsilon_t \qquad (8)$$

where $A_0^* = I_K - \mathrm{A}$. Tracing $\varepsilon_{it}$ innovations of the size of one standard deviation through the system (8) produces orthogonalized impulse responses.

Next let us have a look at $A_0^*$ and the challenge of defining it properly. From the definition of W given above the following holds for $A_0^*$:

$$A_0^* = I_K - \mathrm{A} = \begin{bmatrix} 0 & 0 & \ldots & 0 & 0 \\ \beta_{21} & 0 & \ldots & 0 & 0 \\ \vdots & \ddots & \ddots & & \vdots \\ \vdots & & \ddots & \ddots & \vdots \\ \beta_{K1} & \beta_{K2} & & \beta_{K,K-1} & 0 \end{bmatrix} \qquad (8)$$

where $\beta_{kl}$ are coefficients specifying contemporaneous effect. Just as a reduced form VAR, a VAR consisting from a recursive system of equations can be validly estimated using OLS. In other words, a recursive VAR includes all lagged effects up to order *p* just as a reduced form VAR plus a select set of contemporaneous effects. The first regression for variable $y_1$ is estimated without a contemporaneous effect, whereas the regression for variable $y_2$ includes a contemporaneous effect for variable $y_1$, the regression for variable $y_3$ a contemporaneous effect for variables $y_1$ and $y_2$, and so forth. It follows that the application of both Choleski impulse responses and a recursive VAR requires an ordering of variables relative to instantaneous causation. Since results may differ according to the order selected and since instantaneous causation is difficult to observe from the data, theoretically informed considerations relative to the ordering of variables become of primary importance in the implementation of a VAR-analysis that goes beyond a reduced form VAR.

Whereas Eckstein et al. (1985) have confined themselves to a reduced form VAR, Nicolini (2007) has conducted an analysis of Choleski impulse responses for Malthusian checks based on the variable ordering $Y_t = [b_t, d_t, w_t]^T$. The essential argument behind this ordering is that the effect of a real wage shock on fertility is delayed by the nine months of pregnancy plus the time span between the decision of parents to have a child and conception. This implies that fertility decisions resulting from changes in labour income cannot have an effect within the same year except in very few cases (Nicolini 2007: 107). Implicit in this ordering are three other statements: First, there is no contemporaneous effect of a real wage shock on mortality either (Nicolini 2007: 107). This seems reasonable on the grounds that material conditions until mid-year are largely conditioned by the harvest of the previous year in an agrarian economy. Malnutrition resulting from a harvest failure in year $t$ leads to heightened mortality only with some delay, so that the bulk of the mortality response occurs in year $t+1$ rather than $t$. Second, there is an instantaneous effect of the birth rate on the death rate, but not vice versa. This makes sense if one considers the crude death rate rather than the crude death rate net of infant mortality in the analysis. Because of the high weight of infant mortality in total deaths, a positive fertility shock must be immediately followed by a spike in the death rate. With variable definitions as in the present study this effect is controlled away from the outset, however. Third, the wage rate reacts immediately to fluctuations in the birth and death rates, respectively. This makes sense with respect to the death rate, because other things being equal a mortality shock results in a reduction of the labour supply. By contrast, the effect of fluctuations of fertility on the wage rate operates only more than a decade later when children enter the labour market.

To the extent that the variable ordering $Y_t = [b_t, d_t, w_t]^T$ is warranted it has important ramifications. First, it would invalidate separate estimation of Malthusian checks as done by earlier research and section 4 above on the grounds that the real wage is not an exogenous variable as it is treated by equation (5) but rather an endogenous variable that is instantaneously affected by the vital rates. Estimating the Malthusian checks with equation (5) thus implies a simultaneity bias and leads to invalid estimates. Second, it would also imply that population (as a proxy of labour supply) should be included in a VAR analysis of short-run Malthusian dynamics.

We are thus confronted with the unpleasant situation of a variable ordering that is not convincing in all respects, that puts in doubt the validity of the set of variables included in the VAR, and that threatens to invalidate research designs employed by earlier studies. There are three ways out of this situation. First, one could downplay the problems revealed by this discussion and carry out a VAR with impulse functions that are invariant to the ordering of variables. Such a method has been introduced by Pesaran and Shin (1998) and applied to the historical study of short-run Malthusian dynamics by Crafts and Mills (2009: 78). However, as Pesaran and Shin (1998) point out themselves, the results obtained with variable order invariant impulse responses differ from those produced by impulse responses obtained with a Choleski decomposition of the error covariance matrix. As long as there is some prior knowledge on the causal interaction among the variables concerned the order invariant approach should therefore be avoided. A second option, which leads into a completely different direction, consists in exploring yet another type of VARs, namely a structural VAR. However, this would require more knowledge about the interrelations among the variables concerned, and usually involves more complex estimation techniques. The third option consists in staying with a recursive VAR and Choleski impulse responses, exploring the validity of another variable ordering and checking whether it can be reconciled with earlier approaches to the study of short-run dynamics.

In fact, the variable ordering $Y_t = [b_t, d_t, w_t]^T$ is flawed for at least two reasons. First, Lee (1981: 370–1) has documented a strong negative intra-year relationship between English wheat prices and fertility in 1691–1834, which he interprets as an effect of income on foetal mortality. Consequently, when considering contemporaneous effects within one year the birth rate should be considered as endogenous rather than exogenous to the real wage. Second, we know that during the pre-industrial era nominal wages were rather sticky and that short-term fluctuations in real wages were mainly caused by variations in consumer prices, notably the price of grain. Thus, in five towns with dense information on wages the average coefficient of variation of the silver wage of construction workers was 0.073 in 1763–1792; by contrast, consumer prices show a coefficient of variation of 0.118 in the same period.[2] This implies that in the short run real wages were mainly conditioned by the supply of the products entering the consumer basket; only in the long run did real wages adjust to labour supply (i. e., Malthusian feedback) and labour demand (changes in $\alpha_t$ in equation 1). Relative to contemporaneous effects, then, the real wage should be considered as exogenous, rather than endogenous relative to the birth and death rates.[3]

On the background of these two arguments we implement the variable ordering $Y_t = [w_t, d_t, b_t]^T$ instead of $Y_t = [b_t, d_t, w_t]^T$. In other words, we assume that the real wage is completely exogenous, i. e., that short term fluctuations of wages were not influenced by the non-infant death or birth rates of the same year (because wages were sticky). Likewise, the birth rate should not be able to influence the rate of non-infant deaths in the same year

2 Data as in Pfister (2014). The five towns are Augsburg, Gdansk, Göttingen, Hamburg and Würzburg. The time period was chosen so that the years characterized by war time inflation (1756–1763, after 1792) were excluded.

3 It is also interesting to note that in Germany for the period 1730–1799 Choleski impulse responses based on the variable ordering $Y_t = [b_t, d_t, w_t]^T$ produce a positive response of the real wage on a shock in the birth rate and a negative response on a shock in the death rate (net of infant deaths) in the first period ($t$). Both responses are within the 95 per cent confidence interval bands but have the opposite of the expected sign. This suggests mis-specification in the sense of a failure to capture the contemporaneous effects of the real wage on the vital rates.

because in the wake of data preparation we have corrected deaths for births, yielding non-infant deaths.

Beyond the arguments developed so far the appropriateness of the variable ordering $Y_t = [w_t, d_t, b_t]^T$ is supported by tests for Granger causality. Variable $y_1$ Granger-causes $y_2$ if lagged effects of $y_1$ on $y_2$ are stronger than lagged effects of $y_2$ on $y_1$. Table 2 reports bivariate tests for Granger causality. The lag length is derived from the same information criteria that are applied in determining VAR order below.

*Table 2: Granger causality tests for vital rates and the real wage, 1730–1870* (lag length=2; F-statistics of Wald tests, P values in parentheses)

| Null hypothesis | F-statistic (P value) |
|---|---|
| CDRn0 does not cause CBR | 4.51 (0.013) |
| CBR does not cause CDRn0 | 3.50 (0.032) |
| ln (real wage) does not cause CBR | 17.23 (<0.001) |
| CBR does not cause ln (real wage) | 0.07 (0.932) |
| ln (real wage) does not cause CDRn0 | 3.32 (0.039) |
| CDRn0 does not cause ln (real wage) | 1.08 (0.342) |

*Sources:* Own calculation based on sources for Figure 1; variable definitions as in Table 1; outliers changed to zero.

The tests suggest Granger-causality from the real wage to the birth and the death rates, respectively, and — albeit weakly — from the death rate to the birth rate. Whereas we fully acknowledge that contemporaneous causation, which at issue here, differs in principle from causal patterns suggested by the structure of lagged effects, we do not see a reason why the latter patterns should be completely overturned when considering short-run effects in the intra-year time frame. It can be stated at any rate that the variable ordering we consider as an appropriate representation of contemporaneous effects on substantive grounds is fully compatible with the causal pattern suggested by lagged effects.

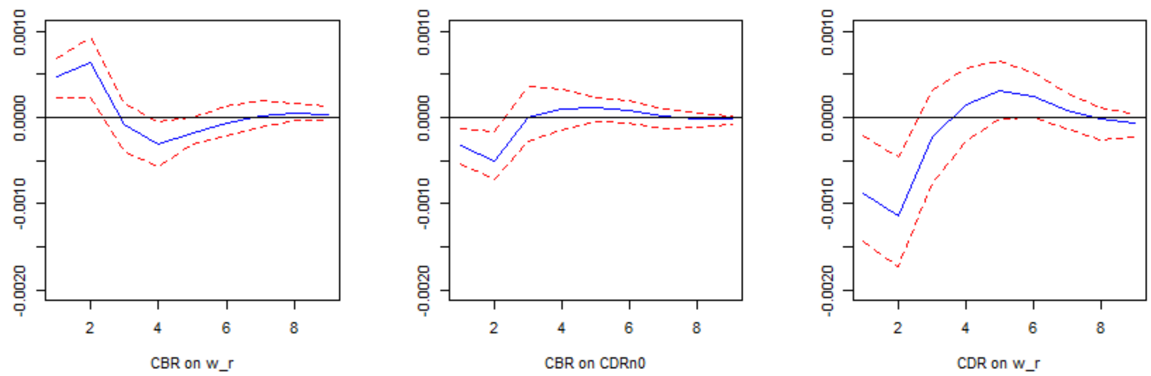
The variable ordering $Y_t = [w_t, d_t, b_t]^T$ also has wider implications beyond the mere estimation of a recursive VAR and the Choleski impulse responses. In particular, separate estimates of the Malthusian checks along the lines of equation (5) above appear as correct subsets of this recursive VAR. Since the real wage is now considered as contemporaneously exogenous the inclusion of a contemporaneous effect of this variable in the regression equation of both the birth and the death rate is valid.

A few minor issues relate to the implementation of VAR analysis in our specific case. We confine discussion of results to the series in which outliers and data points with high leverage have been set to zero. Results obtained with the original data do not deviate substantially from those shown. For the version of the dataset with outliers removed most information criteria suggest that two lags should be considered, so we report findings for VARs with order 2. Finally, because visual inspection of data series and separate estimation of Malthusian has shown that vital rates were exogenously determined during the era of the Napoleonic Wars we limit VAR analysis to the two sub-periods 1730–1799 and 1815–1870.

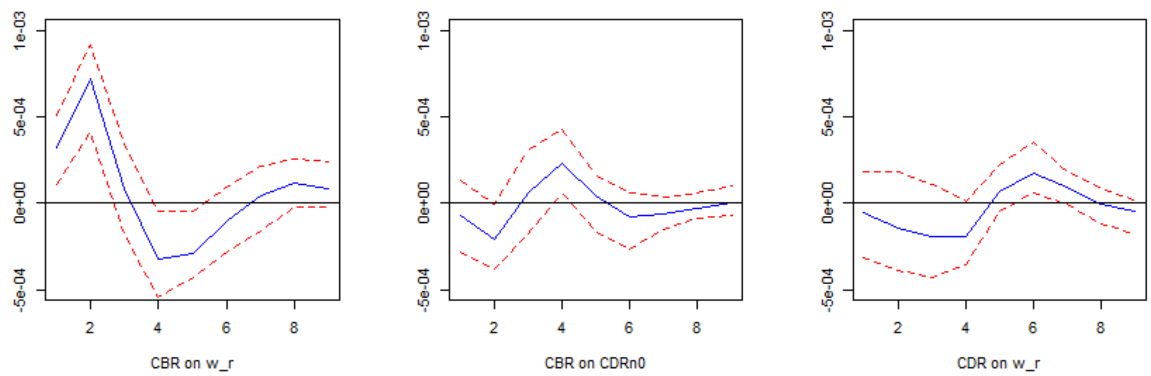
The following findings emerge from the impulse responses shown in Figure 4 and the parameter estimates displayed in Table 3: First, a real wage shock was absorbed by the demographic system essentially within three years, that is, the year of the shock itself and the two following years. Before 1800 there were weak echoes in the two to three years thereafter that are statistically significant in year 4. Given the great weight of younger ages in prevailing mortality patterns the fertility peak occurring in year two of a real wage shock produces a hike in non-infant deaths two years after. The interpretation of the echo of the birth rate is less straightforward; presuming widespread breastfeeding the fertility peak in year two combined with low mortality (including infant mortality) in the same year may have delayed new conceptions for one year (the average lactation period) and hence reduced fertility another year later (Lee 1981: 370).

*Figure 4: Impulse responses of vital rates and the real wage* (Response to Choleski One S.D. Innovations ± 2 S.E.; lag length=)

1730–1799




1815–1870




*Sources:* Own calculation based on sources for Figure 1, variable definitions as in Table 2; outliers changed to zero.

Second, the main results from the separate estimation of the Malthusian checks using distributed lags regression are preserved, but with some modifications: According to the impulse responses in Figure 4 a real wage shock led to an increase in fertility and a decrease in mortality in the same year and one year after until 1800. The preventive check was also weaker than the positive check during this era. In the sub-period 1815–1870 the preventive check was still present, whereas the positive check was weak and not significant statistically. In contrast, the more fine graded results obtained with distributed lags regression yielded statistically significant responses of non-infant mortality to real wage fluctuations albeit only for a minority of sub-periods after 1815 (cf. Figure 3 above). More surprisingly, the results of the VAR analysis suggest that the preventive check re-emerged at similar strength after the Napoleonic Wars. By contrast, distributed lags regression suggests that the strength of the preventive declined over time as well.

*Table 3: Recursive VAR(2) estimate for vital rates and the real wage* (OLS estimates of regression coefficients, absolute values of t-values in parentheses)

| Dependent variable | (1)<br>CBR | (2)<br>CDRn0 | (3)<br>ln (real wage) |
|---|---|---|---|
| *a. 1730–1799* | | | |
| ln (real wage)$_t$ | 0.008* (2.23) | -0.022* (3.37) | |
| ln (real wage)$_{t-1}$ | 0.004 (1.06) | -0.010 (1.28) | 0.417* (2.92) |
| ln (real wage)$_{t-2}$ | -0.006 (1.51) | 0.013$^+$ (1.73) | -0.260$^+$ (1.79) |
| CBR$_{t-1}$ | -0.044 (0.37) | 0.103 (0.45) | 2.582 (0.57) |
| CBR$_{t-2}$ | 0.012 (0.10) | -0.375 (1.61) | 3.119 (0.68) |
| CDRn0$_{t-1}$ | -0.158* (2.34) | | |
| CDRn0$_{t-1}$ | -0.131$^+$ (1.73) | 0.365* (2.68) | -5.235$^+$ (1.99) |
| CDRn0$_{t-2}$ | 0.130$^+$ (1.84) | -0.068 (0.51) | 4.215 (1.62) |
| $R^2$ (adj.) | 0.440 | 0.422 | 0.266 |
| | | | |
| *b. 1815–1870* | | | |
| ln (real wage)$_t$ | 0.005* (3.48) | -0.001 (0.63) | |
| ln (real wage)$_{t-1}$ | 0.006* (2.94) | -0.002 (0.58) | 0.656* (4.27) |
| ln (real wage)$_{t-2}$ | -0.005* (2.52) | -0.001 (0.35) | -0.337$^+$ (1.94) |
| CBR$_{t-1}$ | 0.155 (1.23) | 0.036 (0.20) | -1.320 (0.12) |
| CBR$_{t-2}$ | -0.068 (0.54) | -0.338$^+$ (1.96) | -2.696 (0.25) |
| CDRn0$_{t-1}$ | -0.138 (1.38) | | |
| CDRn0$_{t-1}$ | -0.008 (0.10) | -0.204$^+$ (1.84) | 4.350 (0.63) |
| CDRn0$_{t-2}$ | -0.023 (0.29) | -0.156 (1.39) | 9.402 (1.35) |
| $R^2$ (adj.) | 0.569 | 0.108 | 0.314 |

*Sources:* Own calculation based on sources for Figure 1, variable definitions as in Table 2; outliers changed to zero.
*Note:* * $Prob(T \geq t | H_0) < .05$, $^+<.1$. Dependent variable (dep. var.) means refer to the original, not detrended series.

Third, inspection of the regression coefficients in Table 3 allows identification of the relationships among the variables involved that cause the differences between separate estimation of checks with distributed lags regression and VAR analysis. One important finding of Table 3 concerns the negative contemporaneous effect of non-infant mortality on fertility. It is substantial and statistically significant during the first sub-period, but loses strength and becomes insignificant after 1815, in parallel with the weakening of the positive check (see also the middle panels in Figure 4). This suggests that before 1815 fertility was strongly conditioned by the health of mothers. The apparent decline of the preventive check in Figure 3 is thus mainly caused by the weakening of the presumed health effect in the early nineteenth century.

Thus, a major result of our VAR analysis is that non-observed health effects mediate part of the impact of real wage variations on fertility. In a wider perspective this finding questions the validity of the unconditional elasticity of the birth rate on the real wage as a representation of the preventive check. Recall that the preventive check refers to deliberate action by fiancés and married couples to either accelerate or postpone marriage or a new child. To the extent that the real wage-fertility relationship is mediated by health effects it partly captures one aspect of the positive check rather than giving a pure representation of the preventive check.

# 6. Conclusion

Two major findings emerge from our investigation into the Malthusian checks during the one-and-a-half century before national unification in Germany: First, both the positive and the preventive check existed during the period 1730–1800. The preventive check was much weaker than the positive check, however; eighteenth-century was clearly characterized by a high-pressure Malthusian regime. Note also that while the two checks were relatively strong in comparative perspective they were insufficient to equilibrate population with the decline of labour demand that set in during the 1730s. Population grew at a pace of 0.5 per cent per year in this period despite a falling real wage, thus contributing to a Malthusian disequilibrium.

Second, after the first two decades of the nineteenth century the positive check was weak and statistically unstable, whereas the preventive check persisted until the end of the period of observation in 1870. Combining the results of our econometric analysis with visual inspection of the data suggests that the first two decades of the nineteenth century were characterized by two quite different experiences: The years up to 1815 were a war period. Mortality peaks (and to a lesser degree throughs relative to the birth rate) matched fluctuations of the real wage only to a very limited degree and thus appear as exogenous to a Malthusian system. In part this may stem from imprecisions in the real wage data resulting from poor coverage and the failure to adequately capture the effects of inflationary war finance with the consumer price index. In part, however, war also created mechanisms that exerted powerful effects on demographic variables that were unrelated to short-term Malthusian processes: Poor sanitary conditions during sieges contributed to the emergence of epidemics, whose spread was eased by war-related geographical mobility. War also hindered the smooth operation of markets, which prevented the transfer of food surpluses into deficit regions. Only with the end of war in 1815 did excesses of deaths over births disappear for good. In a way the food crisis of 1816/17 constitutes a defining moment in German demographic history: The eruption of the Tambora volcano in 1815 led to successive harvest failures, which manifested themselves in a dramatic plunge of the real wage in 1817, but it was no more accompanied by an excess of births over deaths. Whereas war led to a situation in which vital rates were temporarily driven by non-Malthusian forces during the first one-and-a-half decades of the nineteenth century the second half of the 1810s brought a definitive weakening of the positive check.

This finding can be juxtaposed with the results of another study that shows a strong increase of labour demand around 1820 and a continuous outward shift at lower pace thereafter, which was capable to offset the negative effect of population growth on labour productivity (Pfister et al. 2012). Taken together, these findings suggest that Germany by and large ceased to be Malthusian by 1820.

Before we put this result in a wider context we would like to point to methodological and theoretical implications of our investigation. We show that earlier applications of VAR to the historical analysis of Malthusian checks have made assumptions on the contemporaneous causal relationships among the variables involved that are incompatible with prior knowledge on these relationships. We implement a recursive VAR that classifies the real wage as exogenous and the birth rate as endogenous in the intra-year time frame, the death rate taking an intermediate position. Such a VAR does not only conform with prior knowledge about the short-term relationships among these variables but also constitutes a natural extension of the separate estimation of Malthusian checks practiced by earlier research.

In addition, VAR analysis suggests that in the German case at least the effect of the real wage on the birth rate operated in part through the non-infant death rate, which we interpret as a proxy for unmeasured health effects on fertility. This implies that the real wage-fertility relationship as it is used in standard Malthusian models imperfectly captures the preventive check, which relates to deliberate action in the form of the timing of marriage and family planning. Therefore, future research should explore extended versions of a Malthusian system that include the marriage rate as an element of the preventive check and model marital fertility.

In comparative perspective, the disappearance of the positive check in Germany during the first two decades of the nineteenth century can be juxtaposed with the fact that most researchers find that the positive check disappeared in England during the second quarter of the eighteenth century if not much earlier (Weir 1984; Nicolini 2007; Crafts and Mills 2009), whereas France continued to have a weak positive check until the middle decades of the nineteenth century (Weir 1984, based on grain prices rather than the real wage as proxy for income). The great variation in the timing of the disappearance of the positive check between these countries suggests considerable diversity among European economies with respect to the transition to a non-Malthusian demographic regime during the early stages of modern economic development.

An outstanding aspect of our findings is that in Germany the disappearance of the positive check predated the onset of the first stage of industrialization c. 1840–1870 by several decades. It was thus not industrialization that saved Germany from the Malthusian trap. Rather, the decade after 1815 was characterized by a rapid integration of grain markets (Pfister et al. 2011). The creation of large territorial states, notably in Prussia and Bavaria, the abolition of internal tariffs, the internal unification of currency systems and programmes of road construction produced a positive institutional shock that promoted market integration (Borchard 1968: 260–78; Otto 2002: 28–93). Grain market integration eased the inter-regional transfer of food surpluses to deficit areas, which not only reduced the effect of local harvest failures but also created a potential for Smithian growth through regional specialization. Regional specialization rendered possible through market integration in turn led to advances in agricultural productivity (Kopsidis 1998), which improved food security in the long run. This may explain why the disappearance of the positive check occurred in close parallel to a strong rise in labour productivity (Pfister et al. 2012). Market integration thus appears as the prime force behind the transition to a non-Malthusian demographic regime in the years around 1820.

To some extent, the transition to a non-Malthusian regime can also be related to the Boserupian argument that a Malthusian disequilibrium leading to rapid population growth promotes the spread of technological innovations (Boserup 1965; Galor 2011: 16). Many innovations in agricultural techniques that were adopted during the early nineteenth century partly in conjunction with increased market orientation both of agricultural and proto-industrial production were labour intensive, such as potato cultivation and stall-feeding. Likewise, the motive to create employment for the labouring poor inspired a number of institutional reforms enacted by state authorities around this time, such as the liberalization of handicraft production, infrastructure creation and land reforms. The population growth of the eighteenth and early nineteenth century thus may have operated as a precondition for the transition to a non-Malthusian regime, but there is no way to see how population growth could have conditioned the exact time point of the transition.

## References


Bass, Hans-Heinrich (1991): *Hungerkrisen in Preußen während der ersten Hälfte des 19. Jahrhunderts*, St. Katharinen: Scripta Mercaturae.

Belsley, David. A., Edwin Kuh, and Roy E. Welsch (1980): *Regression Diagnostics: Identifying Influential Data and Sources of Collinearity*, New York (N.Y.): John Wiley and Sons.

Borchard, Karl (1968): *Staatsverbrauch und öffentliche Investitionen in Deutschland 1780–1850*, PhD dissertation, Universität Göttingen.

Boserup, Ester (1965): *The Conditions of Agricultural Growth: The Economics of Agrarian Change under Population Pressure*, London: Allen and Unwin.

Burhop, Carsten and Guntram Wolff (2005): 'A Compromise Estimate of German Net National Product, 1851–1913 and its Implications for Growth and Business Cycles,' *Journal of Economic History* 65, 613–657.

Crafts, Nicholas and Terence C. Mills (2009): 'From Malthus to Solow: How Did the Malthusian Economy Really Evolve?' *Journal of Macroeconomics* 31, 68–93.

Eckstein, Zvi et al. (1985): 'Short Run Fluctuations in Fertility and Mortality in Pre-Industrial Sweden,' *European Economic Review* 26, 295–317.

Fertig, Georg (1999): 'Marriage and Economy in Rural Westphalia, 1750–1850: A Time Series and Cross-Sectional Analysis,' pp. 243–71 in Isabelle Devos and Liam Kennedy (eds.), *Marriage and Rural Economy: Western Europe since 1400*, Turnhout: Brepols.

Galor, Oded (2011): *Unified growth theory*, Princeton: Princeton University Press.

Galloway, Patrick R. (1988): 'Basic Patterns in Annual Variations in Fertility, Nuptiality, Mortality, and Prices in Preindustrial Europe,' *Population Studies* 42, 275–303.

Galloway, Patrick R. (1994): 'Secular Changes in the Short-Term Preventive, Positive, and Temperature Checks to Population Growth in Europe, 1460–1909,' *Climatic Change* 26 (1994), 3–63.

Gehrmann, Rolf (2000): *Bevölkerungsgeschichte Norddeutschlands zwischen Aufklärung und Vormärz*, Berlin: Berlin.

Gehrmann, Rolf and Maureen Roycroft (1990): 'Quellen und Methoden der Mortalitätsberechnungen,' pp. 51–83 in Arthur E. Imhof (ed.), *Lebenserwartungen in Deutschland vom 17. bis 19. Jahrhundert*, Weinheim: VHC Acta humaniora.

Guinnane, Tim and Sheilagh Ogilvie (2008): 'Institutions and demographic responses to shocks: Württemberg, 1634–1870,' Yale University, Dept. of Economics, Working Paper 44.

Kopsidis, Michael (1998), 'Der westfälische Agrarmarkt im Integrationsprozeß 1780–1880. Phasen und Einflußfaktoren der Marktentwicklung in historischen Transformationsprozessen,' *Jahrbuch für Wirtschaftsgeschichte*, 1998/2, 169–198.

Kraus, Antje (1980): *Quellen zur Bevölkerungsstatistik Deutschlands 1815–1875*, Boppard am Rhein: Boldt.

Lee, Ronald D. (1981): 'Short-Term Variation: Vital Rates, Prices, and Weather', pp. 356-401 in Wrigley and Schofield (1981).

Lee, Ronald D. and Michael Anderson (2002): 'Malthus in State Space: Macro Economic-Demographic Relations in English History, 1540 to 1870,' *Journal of Population Economics* 15, 195–220.

Lütkepohl, Helmut (2007): *New Introduction to Multiple Time Series Analysis* (Berlin: Springer, 2nd printing).

Møller, Niels Framrose and Paul Sharp (2008): 'Malthus in Cointegration Space: A New Look at Living Standards and Population in Pre-Industrial England,' University of Copenhagen, Department of Economics, Discussion Papers 08-16.

Nicolini, Esteban A. (2007): 'Was Malthus Right? A VAR Analysis of Economic and Demographic Interactions in Pre-Industrial England,' *European Review of Economic History* 11, 99–121.

Otto, Frank (2002): *Die Entstehung eines nationalen Geldes: Integrationsprozesse der deutschen Währungen im 19. Jahrhundert*, Berlin: Duncker und Humblot.

Pesaran, H. Hashem and Yongcheol Shin (1998): 'Generalized impulse response analysis in linear multivariate Models,' *Economics Letters* 58, 17–29.

Pfister, Ulrich (2014): 'The timing and pattern of real wage divergence in pre-industrial Europe: evidence from Germany, c. 1500–1850,' WWU Münster, unpublished manuscript.

Pfister, Ulrich (2010): 'Consumer Prices and Wages in Germany, 1500–1850,' WWU Münster, Department of Economics, CQE Working Paper 15.

Pfister, Ulrich and Georg Fertig (2010): 'The Population History of Germany: Research Agenda and Preliminary Results,' MPIDR Working Paper WP 2010-035.

Pfister, Ulrich, Jana Riedel and Martin Uebele (2012): 'Real Wages and the Origins of Modern Economic Growth in Germany, 16th to 19th Centuries,' *European Historical Economics Society, Working Paper* 17.

Pfister, Ulrich, Martin Uebele and Hakon Albers (2011): "The Great Moderation of Grain Price Volatility: Market Integration vs. Climatic Change, Germany, Seventeenth to Nineteenth Centuries," Contribution to the BETA-Workshop in Historical Economics, Strasbourg, May 2011.

Post, John D. (1977): *The last great subsistence crisis in the Western world*, Baltimore: Johns Hopkins University Press.

Post, John D. (1985): *Food shortage, climatic variability, and epidemic disease in preindustrial Europe: the mortality peak in the early 1740s*, Ithaca: Cornell University Press.

Stier, Bernhard and Wolfgang von Hippel (1996): 'War, Economy and Society,' pp. 233–262 in Sheilagh C. Ogilvie (ed.), *Germany: a new social and economic history, vol. 2: 1630–1800* (London: Arnold).

Stock, James H. and Mark W. Watson (2001): 'Vector Autoregressions,' *Journal of Economic Perspectives* 15, 4, 101–115.

Weir, David (1984): 'Life under Pressure: France and England 1670–1870,' *Journal of Economic History* 54, 27–47.

Wrigley, Edward A. and Roger S. Schofield (1981): *The Population History of England 1541–1871: A Reconstruction*, Cambridge: Cambridge University Press.