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Abstract

The study develops a real wage series for Germany c. 1500-1850 and analyzes its relationship with population size. From 1690 data density allows the estimation of a structural time series model of this relationship. The major results are the following: First, there was a strong negative relationship between population and the real wage until the middle of the seventeenth century. The dramatic rise of material welfare during the Thirty Years' War was thus entirely due to the war-related population loss. Second, the relationship between the real wage and population size was weaker in the eighteenth than in the sixteenth century; the fall of the marginal product of labor was less pronounced, and the beginning of the eighteenth century saw a marked increase of labour demand. Third, labor productivity underwent a strong positive shock during the late 1810s and early 1820s, and continued to rise at a weaker pace during the following decades. This growth was only temporarily interrupted by negative shocks during the late 1840s and early 1850s. Results two and three suggest the onset of sustained economic growth well before the beginnings of industrialization, which set in during the third quarter of the nineteenth century.

JEL codes: C22, C32, J2, J31, N33

Keywords: Standard of living, Malthusian economy, state space model

1 Introduction

The evolution of material welfare in Germany before the late nineteenth century remains little studied (cf. Broadberry & Burhop (2010)). Given that Germany constituted an important part of the European economy already during the preindustrial era research that fills this gap has the potential to significantly improve our knowledge on a major aspect of pre-modern economies. First, the construction of a real wage index based on information from a plurality of cities complements our knowledge on the long-term evolution of material welfare during the centuries preceding industrialization in other European countries, notably England (cf. Clark (2005); Clark (2007)). Second, an investigation of the relationship between the real wage and population can disentangle the effects of variations of population size and of changes in the demand for labor on wage levels (Lee & Anderson (2002), Crafts & Mills (2009)). Since under standard assumptions labor demand is equal to the marginal product of labor and since labor productivity constitutes an important element of most aggregate production functions, such an analysis provides at least indirect evidence on long-term patterns of economic growth. In particular, it can trace the transition from a state with static labor productivity in which the level of material welfare was mostly conditioned by fluctuations of population size to a situation in which sustained increases in labor productivity dampened and finally erased the negative effect of population growth on welfare.

In this study we develop new indices of real wages in Germany for the period 1500-1850 based on wage and price information from ten to sixteen cities. A salient result is the absence of a clear trend before the late nineteenth century: Only with the transition to sustained industrial growth from the 1880s did the real wage return to the level prevailing at the beginning of the sixteenth century and finally surpass it. There was a clear break in the regime of the wage-population relationship some time after 1650, however. Until the middle of the seventeenth century there existed a fairly close negative relationship between the real wage and population size of the same order of magnitude as found for England, suggesting static labor productivity. The implementation of a structural time series model for the period 1690-1870 by contrast shows a much flatter slope of the marginal product of labour as well as an outward shift of labor demand during at the beginning of the eighteenth century, which was sustained over several decades. There also occurred a strong positive shock on labor productivity around 1820 that was followed by a sustained rise thereafter. Yet, labor productivity growth did not increase with the emergence of industrial leading sectors in the 1840s and 1850s. These results lend support to the thesis that aggregate growth underwent little acceleration during the early phases of industrialization (for the British case see Crafts & Harley (1992), Harley (1999)) and that earlier development, particularly in the form of Smithian growth, facilitated an endogenous transition to modern economic growth.

The article is organized as follows: Section 2 briefly presents the new real wage indices while section 3 investigates the wage-population relationship, in particular through the implementation of a structural time series model. Section 4 develops an interpretation of the results, and section 5 concludes.

2 Data

Our study draws on wages of unskilled building workers from sixteen towns and on prices of eleven consumer goods from ten towns. Most towns are located within the borders of present-day Germany, except for Gdansk and Strasbourg. Gdansk was a hanseatic town that enjoyed high autonomy within the Polish kingdom and came under Prussian dominance in 1793. Strasbourg, originally an independent town within the German Empire, is included in our dataset until 1681 when it was taken by the French crown (for details on sources, see Pfister (2010), pp. 28-36).

Nominal wages are converted into real wages by using the consumer price index (CPI) developed by Pfister (2010), pp. 2-12. It largely follows the methodology of Allen (2001) in that the CPI is defined as the silver price of a basket with fixed quantities of eleven goods consumed annually by an adult town dweller. In total there are ten towns for which a CPI can be constructed in this way over some period of time. Coverage varies considerably, however, between 1500 and 1850: At both ends of the observation period information density is much less satisfactory than in the middle. From two towns in 1500 coverage rapidly rises to five in 1510 and six in 1535. It oscillates between five and seven towns until 1800 and then rapidly falls to three (Göttingen, Leipzig and Nuremberg).

A Laspeyres index such this CPI is by definition unable to capture the possible effect of changes in consumption patterns on the price level. However, German diet underwent three major changes during the period of observation, which were related to progressive shifts to cheaper substitutes as relative prices changed: First, the sixteenth century saw a drastic decline of meat rations and their partial substitution by vegetable foods, which may have cheapened consumer prices by about 8 percent between 1500 and 1600. Second, potato cultivation began a rapid spread from the late eighteenth century. Its substitution of foods based on grains cheapened calorie intake by working classes by about 4 percent between 1800 and 1850. Finally, from the mid-seventeenth century tropical groceries made a growing contribution to everyday consumption whose extent is very hard to quantify, however. At least it can be said that the substitution of calories originating from other foods by sugar may have reduced the cost of living by about 2 percent between 1800 and 1850 (Pfister (2010), pp. 7-9). However rough and imprecise this assessment of changes in consumption patterns may be its consideration is useful for a correct representation of long-term developments both of the costs of living and of material welfare. Accordingly, a national aggregate of town-specific CPIs has been developed in two variants: One with a stable basket and one in which the values backwards from 1600 and forward from 1800 are adjusted exponentially so that the index value is 8 percent higher than the variant with a constant basket in 1500 and 6 percent lower in 1850, respectively. The same adjustment will be applied to the real wage series.

The validity of a national CPI based on silver prices in a restricted number of localities may be questioned on several grounds. First, market integration in Germany was weak before the middle decades of the nineteenth century, so that the national CPI may not adequately capture the price level in towns for which only wage data are available. Second, the silver content of local currencies is not always known with satisfactory precision so that silver prices (and silver wages) are inaccurate (Metz (1990), pp. 158-172). Third, markets for metallic currencies were not well integrated in the sixteenth century if not until much later (Gerhard & Engel (2006), pp. 43-44, Boerner & Volckart (2011)).

To take into account these arguments the real wage is calculated in two variants. In the first variant silver wages in individual towns are deflated by the local CPI. Because the silver conversion ratio is the same for both wages and prices, the above objections do not hold in this variant. Note that in contrast to a usual real wage index this one has an intuitive meaning: It designates the fraction of the annual consumer basket that can be bought with a day wage. Thus, a value of 0.010 means that an unskilled building laborer needed to work 100 days at the remuneration of a summer wage to purchase the annual consumer basket for one person. In the second variant silver wages of individual towns are deflated by the national CPI. Since this index includes wage data from towns without information on consumer prices and since we do not know to what extent the national CPI is representative of all towns the intuitive meaning of this variant of the real wage is less straightforward. This also implies a trade-off between methodological precision and information content: The real wage index based on locally deflated information does not suffer from the problems arising from the conversion of prices and wages to silver equivalents, but the index based on silver wages deflated by the national CPI contains about 35 percent more data points and therefore may provide better coverage of national wage trends. On this background all estimates below are carried out separately for the two real wage series.

In the variant with wages deflated by the respective local CPI the dataset is restricted to towns and years for which a CPI can be calculated. From 1535 to the end of the eighteenth century real wages can be calculated in principle for five, in 1583-1602 even for six cities. There are many gaps, however, particularly with respect to the first phase of the Thirty Years' War (1618-1630), when coverage shrinks to three towns. The first ten years of the observation period are also covered by only three towns, and information again becomes scarce with the end of the Ancien regime; the analysis of the period from 1811/12 is based exclusively on three towns. The inclusion of wage data from towns for which there is no price information increases coverage by one case up to the 1550s and by another one for the first half of the eighteenth century. For the century 1750-1850 data density increases substantially; coverage of 1750-1790 rises to 10-12 towns and still amounts to eight towns from the 1810s. Because of the many gaps in the data particularly during the first 150 years of the observation period data for both variants were aggregated into centered five year means (except 1500-1502 and 1848-1850). From the second half of the seventeenth century data density allows the construction of yearly indices; for the analysis below we constructed series at annual frequency starting in 1690.

Centered five year means and yearly values of real wages on the level of individual towns were aggregated into national indices using panel regression with fixed effects for cities and years (for details of data aggregation, see Pfister (2010), pp. 12-18). Differently from Pfister (2010) all series were scaled to the respective mean calculated on the basis of city fixed effects, which explains small differences in levels between different versions of the real wage series (cf. Figure 1). Estimates for the indices relating to five-year periods were carried out both using OLS and Weighted Least-Squares (WLS) regression; in the latter case observations were weighted with the number of years with data within each five-year period. The subsequent discussion draws exclusively on the results obtained with WLS, but comparison with the results generated with OLS is used to identify periods in which index values strongly depend on very few data.

Data inspection shows that the implementation of this design requires a control for idiosyncratic positive shocks experienced by individual towns by the introduction of additional city dummies for separate periods in two cases. The first relates to Hamburg, whose real wage rose drastically in the 1650s to levels comparable with Amsterdam and London, probably as a consequence of the ending of war and the rise of the North Sea trading system.[1] Hence, two city dummies were defined for Hamburg, one for the period up to 1648-1652 and the other from 1653-1657. This leads to an underestimation of the general peace shock experienced by the German economy after the conclusion of the Thirty Years' War (1618-1648): A WLS estimate that excludes Hamburg shows an increase of 23.9 percent from 1648-1652 to 1653-1657, whereas the estimate with two Hamburg dummies produces an increase of only 14.6 percent. Therefore, the series based on locally deflated wages that is used henceforth is adjusted upwards so that its increase matches the rise experienced by the towns other than Hamburg.[2]

The second positive shock experienced by an individual town occurred in Munich at the beginning of the nineteenth century: In 1808-1812 the silver wage deflated by the national CPI exceeded the level recorded in the mid 1790s by about 68 percent (no local CPI can be constructed for this period). This positive shock may have been related to successful state-building; the Napoleonic period saw a dramatic expansion of Bavaria's territory and the enactment of far-flung institutional reforms that created a centralized state (Spindler & Kraus (2002), pp. 4-95). In analogy to the procedure applied in the case of Hamburg a separate town dummy was introduced for Munich from 1808-1812, which corresponds to the assumption that the shock experienced by this town was marginal within the context of the German economy as a whole.

Figure 1 presents the main series on which the subsequent analysis relies. These are, first, a WLS estimate based on wages deflated by the respective local CPIs corrected for the peace shock from 1648-1652 to 1653-1657 and adjusted for the effects of changes in consumption patterns in the sixteenth and early nineteenth century, respectively (thin broken line in Figure 1). The second series consists of a WLS estimate based on the extended dataset of silver wages deflated by the national CPI adjusted for the effects of changes in consumption patterns (bold solid line in Figure 1). Where appropriate, two town-specific dummies for Hamburg and Munich are introduced. Finally, Figure 1 also shows annual series estimated with OLS from 1690 both for wages deflated by the respective local CPI (thin dotted line) and for the extended dataset of silver wages deflated by the national CPI (thin solid line). To give an impression of the evolution of the real wage after the end of the observation period, the real wage index of Gömmel (1979) is spliced to the annual series based on silver wages deflated by the national CPI in 1850.

Deviations between different index estimates for the same year can be interpreted as signalling a high degree of uncertainty resulting from low data density. This relates in particular to the real wage level at the beginning of the sixteenth century and the slope of its subsequent fall. The

[1]Israel (1989), chs. 3, 6. The implied mean value of the real wage in Hamburg from 1653-1657 is 0.019 (Pfister (2010), p. 39; estimate based on locally deflated real wages). During the 1690s and the second quarter of the eighteenth century the real wage in Amsterdam and London averaged 0.019-0.020 (Allen (2001), recalculated following the methodology of the present study).

[2]The extended series based on silver wages deflated by the national CPI shows an extremely strong increase of 35.4 percent in 1648-1652 to 1653-1657 if Hamburg is left aside. We explain this with strong reductions in the price level in Hamburg and Strasbourg, which both are represented in the national CPI. Given the imprecision of this design we decided not to adjust the extended series with two Hamburg dummies from 1653-1657.

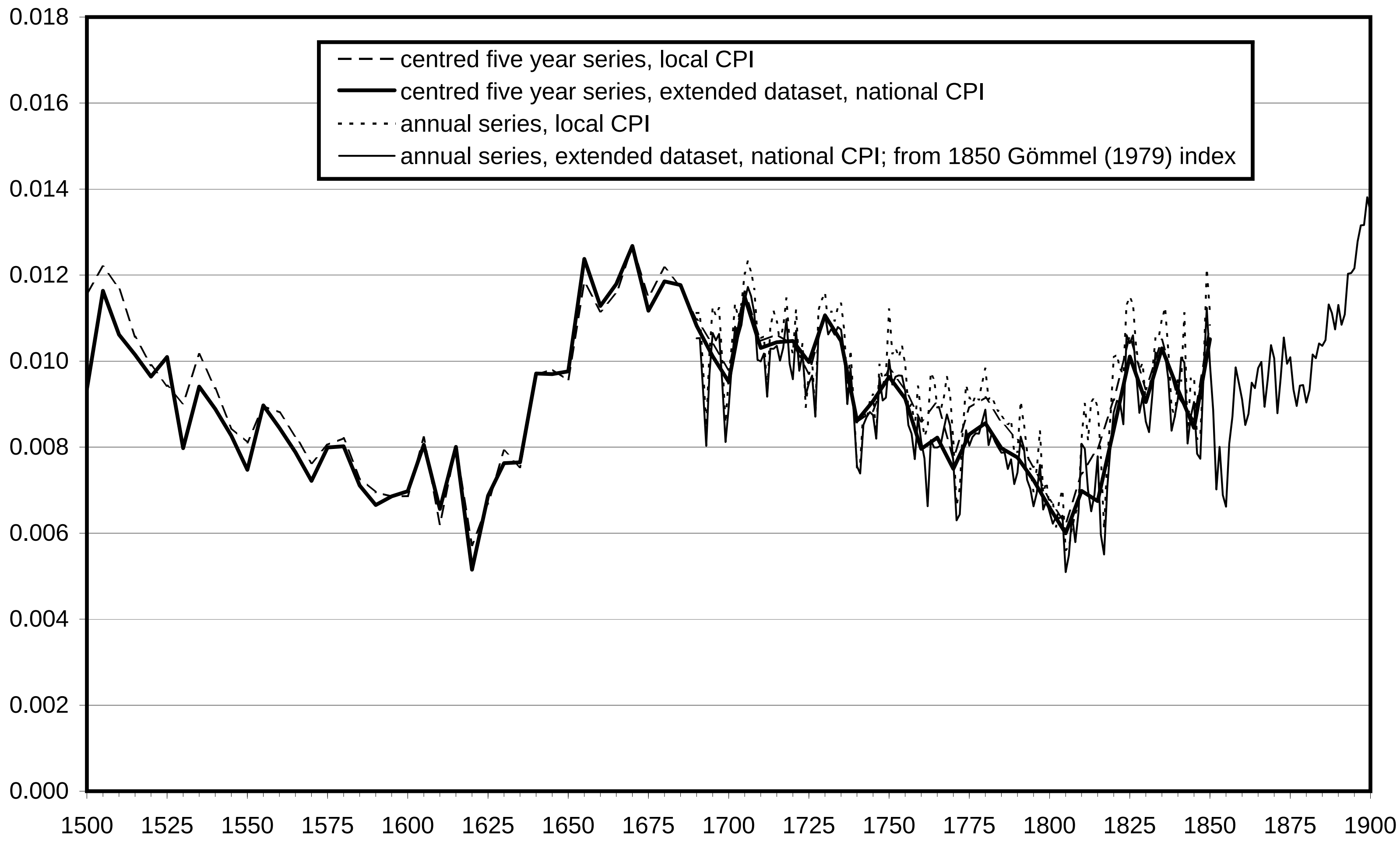


Figure 1: Alternative real wage series, 1500-1850/1900. Vertical axis: Proportion of the annual basket of consumer goods that can be purchased with a summer day wage of an unskilled urban building worker. *Sources:* Gömmel (1979), Pfister (2010).

main reason for the discrepancy between different indices during this period is that the real wage in Xanten, for which no local CPI can be constructed, actually rises during the first half of the sixteenth century, whereas it falls in all other towns.[3] Consequently, the difference between the two index estimates in 1500-1502 is 18.2 percent. Because of this large difference the later analysis will take as a starting point the values in 1503-1507 and 1508-1512, which rely on more data points and show a much smaller discrepancy between different specifications.

Deviations between different series - particularly between OLS and WLS estimates - are again large in 1610-1620. This period was the culmination of the *Kipper und Wipper* era, a time of competitive coin debasement, so that price and wage data are unreliable (cf. Kindleberger (1991)). During the rest of the observation period there exist three major discrepancies between different specifications. First, some uncertainty surrounds the exact extent of the peace shock occurring in 1648-1652 to 1653-1658 as the exact result depends strongly on the treatment of Hamburg (see above). Second, the variant based on silver wages deflated by the national CPI is more pessimistic for the late eighteenth century, particularly the 1760s, the mid 1770s and the 1780s. Third, there is a new clustering of discrepancies between WLS and OLS estimates in the five year periods centered on 1805, 1810 and 1815. They are related to relatively low data density during a period of strong real wage fluctuations, in particular to an unequal coverage of wages during the major food crisis in 1816/17. The estimate for 1813-1817 based on locally deflated real wages, which suggests smooth recovery from the disruption caused by the Revolutionary and Napoleonic wars, appears implausibly high, and the lower value derived from the extended data base of silver wages deserves more credence.

Before developing an interpretation of the evolution of the real wage it is useful to compare the present series with the results of earlier studies. Almost no research exists for the early modern period. For the sixteenth century, at least, the fall of the grain wage in six towns (three of which being also part of the present investigation) by about 48 percent recorded by Abel (1978) and others may provide some kind of yardstick.[4] According to this study real wages fell by about 40 to 43 percent between 1503-1507 and 1598-1602. Since the grain wage takes into account neither the possibility of a decline of the relative price of labor-intensive against land-intensive consumer goods nor changes in consumption patterns, one expects the grain wage to fall somewhat more than a real wage index. The results obtained with the present real wage indices and the information on the grain wage are thus mutually consistent.

More research exists on the first half of the nineteenth century. The standard reference certainly is Gömmel (1979). Gömmel uses nominal wage information from eight towns (six of which being also covered by the present study) plus wages from cotton mills and deflates this composite nominal wage series by the consumer price index of Nuremberg. However, this town was characterized by an exceptionally strong increase of firewood prices from the 1810s, which led to an atypically steep rise in consumer prices (Pfister (2010), p. 7). As a consequence, Gömmel's real wage in-

[3] Grain prices are available, though, and the grain wage also displays a rising trend. The trends of the wage deflated by the national CPI and the wage deflated by local rye prices are thus mutually consistent.

[4] This is derived from the graphical representation of the evolution of the grain wage in five towns from 1491-1510 to 1591-1610 given in Abel (1978), pp. 140-141, the mean reduction being about 45 percent, plus the change of the grain wage in Nuremberg from 1496-1504 to 1596-1604 to the amount of -66.8 percent (Gömmel (1985), pp. 273-174, Bauernfeind (1993), pp. 438-441).

dex is higher than the one of this study in 1823-1827 and particularly in 1808-1812 (30 percent; Gömmel's series starts in 1810), producing a much more pessimistic assessment of material welfare development during the early nineteenth century than the present investigation (cf. Figure 2). Deflating Gömmel's nominal wage series with our national CPI produces a rather different picture, however: The revised Gömmel index and the real wage indices of this study display almost the same values in 1810, and for the remaining years the former follows closely the series based on silver wages deflated by the national CPI. Unless further research demonstrates that Nuremberg's experience was widely shared by other parts of Germany and that the price information used by this study underrates the rise of energy prices during the early nineteenth century, the present indices and the revised Gömmel series deserve more credence than the original Gömmel index.

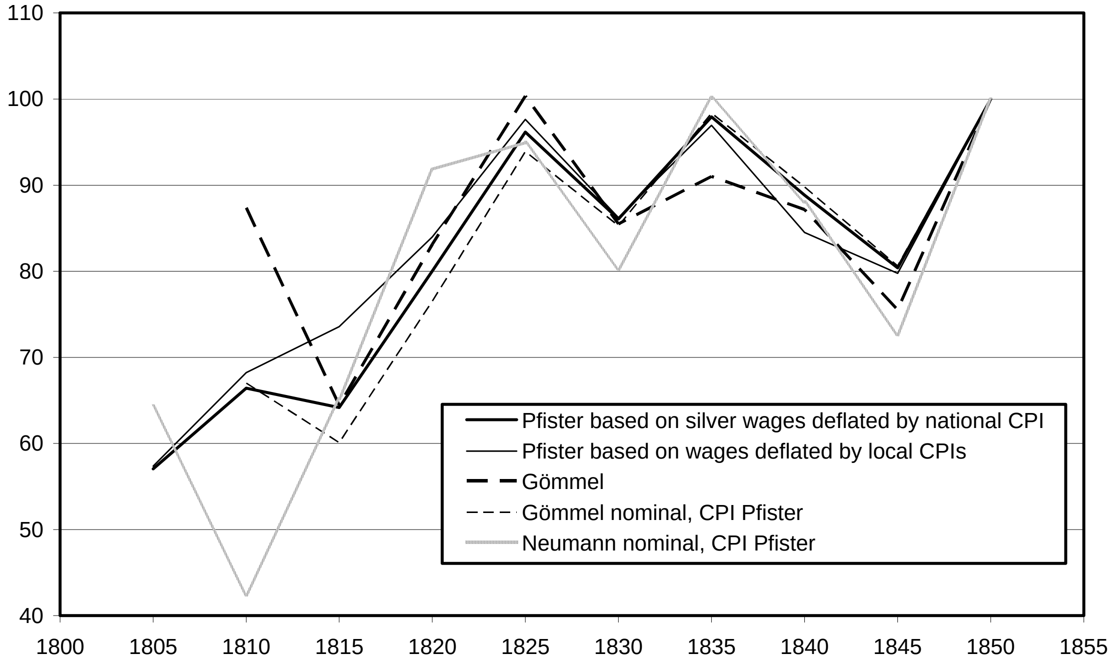


Figure 2: Alternative real wage indices, first half of the nineteenth century (centered five year means). *Sources:* Gömmel (1979), Pfister and Fertig (2010).

Another point of reference is Neumann's (1911) investigation into the wages of rural laborers in Prussia. It is based on about 370 pieces of information on wages in localities, administrative units or whole provinces at different points in time, with a heavy clustering in the late 1840s (about one third of all data points). The nature of the information is heterogeneous in the sense that it often relates to different types of work during different seasons of the year. For the purpose of the present study these data were recompiled using the author's original standardization to a yearly average. A nominal wage series was constructed following the procedure used for creating the indices of this study. This series was then deflated by the national CPI (Pfister (2010), pp. 38, 41).

The major deviation with respect to the other indices displayed in Figure 2 occurs in 1808-1812; however, this value is based on only two administrative units and, therefore, should be discarded from the analysis. Most other values are in the same order of magnitude as the indices of the present study and Gömmel's revised real wage index, respectively. Nevertheless two nuances stand out:

First, the Neumann index is somewhat lower than the other series in the five year periods centered on 1830 and 1845, which comprise serious food crises. This reflects the fact that harvest failures affect rural workers not only through a decline of the food supply but also through a decline of employment opportunities and, hence, food entitlements. By contrast, urban workers, who dispose of incomes that depend at worst indirectly from agricultural business cycles, suffer only from the deterioration of the food supply (Bass (1991), pp. 27, 87-88).

Second, during normal times the wage index of rural labor was above the one for urban construction workers, and the difference is larger at the beginning of the period than towards its end (see notably 1803-1807 and 1818-1822). This implies that rural wages developed less favourably than the remuneration of urban labor during the first half of the nineteenth century: From the low point in 1803-1807 to 1848-1850 real wages of urban workers rose by 72 to 74 percent while those of rural workers in Prussia rose by only 52.3 percent. This finding of a rising urban-rural wage gap is consistent with the acceleration of the pace of urbanization during the first half of the nineteenth century (Pfister (2011), p. 5).

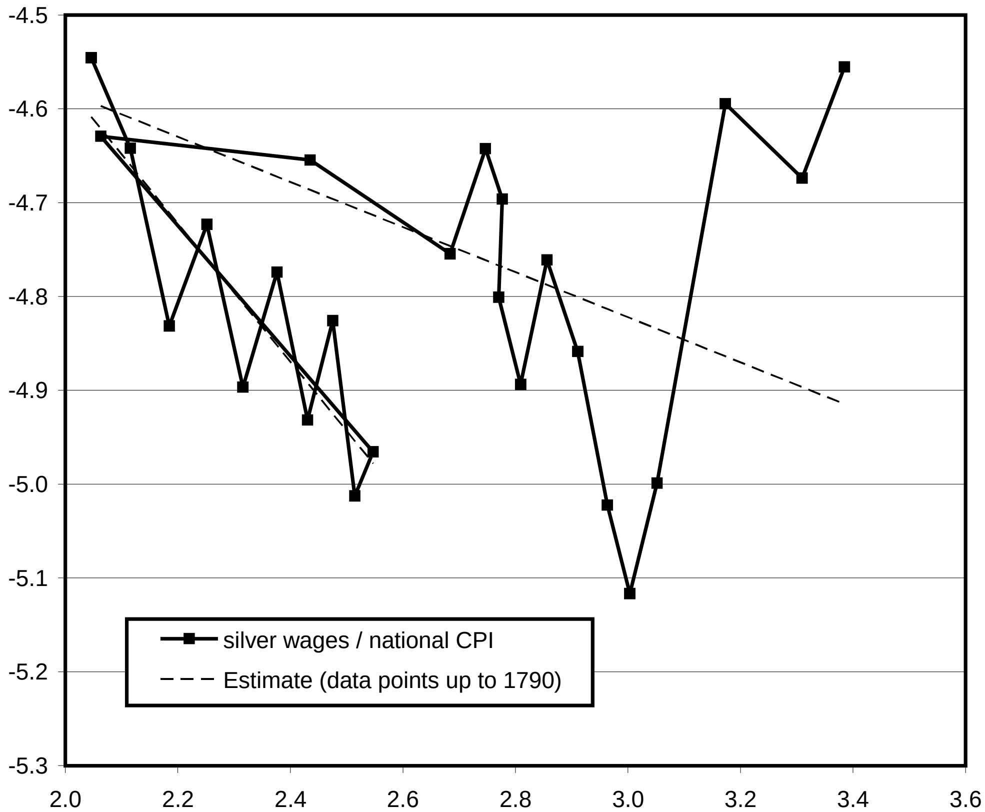


Figure 3: Population size, 1510-1870 (millions). *Source:* Pfister and Fertig (2010)

Apart from wages this study draws on two series of population size (Figure 3). The first is largely based on estimates provided by earlier studies that are homogenized with respect to geographic coverage. They cover the long period 1510-1850 at intervals of ten years and more.[5]

[5]The years covered are 1510, 1520, 1530, 1540, 1550, 1560, 1570, 1580, 1590, 1600, 1650, 1700, 1740, 1750, 1755, 1765, 1770, 1780, 1790, 1800, 1805, 1815, 1825, 1840 and 1850; Pfister & Fertig (2010), pp. 5 (Table 1, columns 2 and 3), 8.

Particularly the estimates for 1650 and 1700 are based on a limited amount of information and must be considered as very imprecise, therefore. The second series covers the period 1690-1870 at annual intervals. From 1840 it is based on Kraus (1980), p. 338; for earlier years, annual figures are extrapolated by combining the estimates of the first series with annual numbers of births and deaths. Back to 1730 the data are highly consistent (Pfister & Fertig (2010), p. 28). In 1690-1730 information density is much lower than in the later period, and data consistency is limited. For this reason, data for this period are plotted as dotted line in Figure 3, and we treat these years seperately in the following analysis.

3 Analysis

A straightforward way to understanding the long-term trajectory of the real wage is to relate it to the demand and supply of labor. Following standard practice (Lee & Anderson (2002), pp. 197, 205; Crafts & Mills (2009), p. 81) we base our analysis on the following wage equation

$$w_t = \alpha_t + \beta p_t + s_t, \quad t = 1, \dots, T \tag{3.1}$$

in which w_t denotes the natural log of the real wage and p_t the natural log of population. α_t refers to the demand for labor, which in turn is determined by the level of labor productivity prevailing in the economy. The parameter β denotes the elasticity of the real wage with respect to labor. Given a falling marginal product of labor, β should be negative. Finally, s_t captures short-term disturbances stemming from subsistence crises and epidemics. Hence, the real wage is determined by the intersection between labor supply and demand plus short-term disturbances to the labor market.

In a pre-modern economy with static technology α_t is constant over time. Therefore, in order to get a first and very preliminary impression of the underlying data generating process we investigate the linear relationship between the real wage and population size. Hence, Figure 4 plots the natural log of the real wage against the natural log of population size (series covering 1510-1850 at longer intervals). The trajectory of the wage-population relationship from the sixteenth to the mid-nineteenth century suggests the existence of three distinct structural periods: First, a strong negative relationship during the sixteenth century, second, a much weaker but still negative relationship during the second half of the seventeenth and the eighteenth centuries and, third, a breakup of the wage-population link at the beginning of the nineteenth century.

This impression can be formalized by performing a simple OLS regression of w_t on p_t for the available data points up to 1790 including an interaction effect with a time dummy:

$$w_t = \alpha + \delta D_t + \beta p_t + \gamma p_t D_t + e_t, \quad e_t \sim \text{iid}(0, \sigma^2) \tag{3.2}$$

in which the dummy variable D_t takes on the value 1 from 1650 onwards and 0 otherwise. γ measures the interaction effect. The estimation is conducted separately for different specifications of the real wage series (centered five year means). The results are presented in Table 1. Despite the small sample size all regression coefficients are statistically significant.

For the period up to 1600 (the last obeservation before 1650) Table 1 suggests an elasticity of the real wage on population in the order of magnitude of $\tilde{\beta} = -0.8$ if wage indices adjusted for

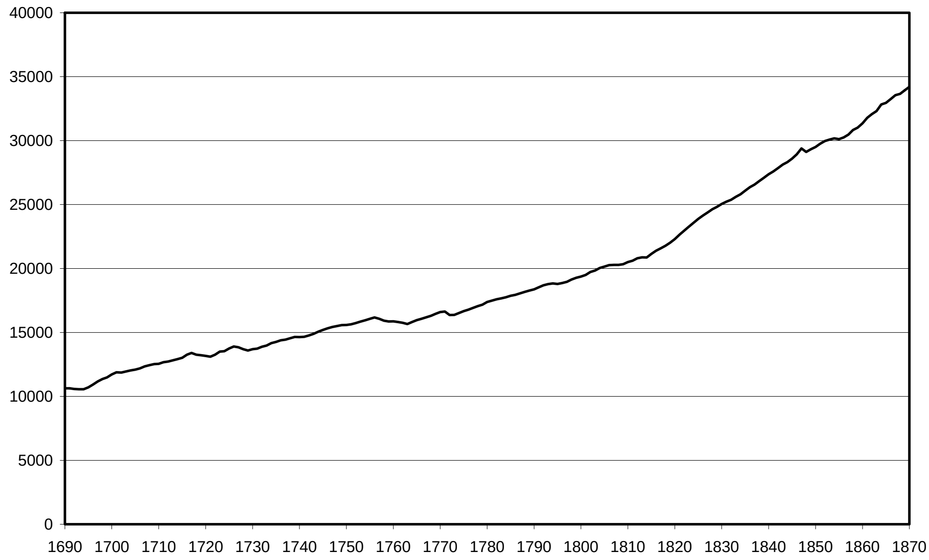


Figure 4: The trajectory of ln real wage (vertical axis) and ln population size (horizontal axis).

Table 1: OLS estimation results of the relationship between real wages and population size, Eq.(3.2), 1510-1790 (19 obs.)

	(1)	(2)	(3)
constant (α)	-2.3031	-2.7114	-3.1010
	(0.3162)	(0.3155)	(0.3483)
time-dummy: from 1650 (δ)	-1.9638	-1.6174	-1.0511
	(0.3922)	(0.3912)	(0.4319)
population (β)	-1.0157	-0.8816	-0.7369
	(0.1356)	(0.1353)	(0.1494)
time-dummy*population (γ)	0.8721	0.7380	0.5146
	(0.1610)	(0.1606)	(0.1773)
$\bar{R}^2$	0.757	0.713	0.631
$\ln L$	25.738	25.783	23.904
DW-stat	2.588	2.600	2.490

Note: Estimation results are presented for different real wage series: column (1): deflated by local CPI, unadjusted for changes in consumption patterns; column (2) deflated by local CPI, adjusted for changes in consumption patterns; column (3): deflated by national CPI, adjusted for changes in consumption patterns. Population size refers to the series based on earlier estimates at intervals of ten and more years. Standard errors are given in parentheses. $\bar{R}^2$ denotes the adjusted R^2, $\ln L$ is the loglikelihood value and DW-stat denotes value for the Durbin-Watson test statistics.

changes in consumption patterns are considered (columns (2) and (3)). By contrast, the elasticity of the unadjusted wage on population is $\tilde{\beta} = -1.02$ (column (1)), which corresponds to the figure found for preindustrial England (Lee & Anderson (2002), p. 210, Clark (2007), p. 121, Crafts & Mills (2009), p. 84). For the period 1650-1790 the sum of the base and interaction effects ($\tilde{\beta} + \tilde{\gamma}$) suggests a much more modest negative reaction of the real wage on population growth with an elasticity in the range of -0.15 to -0.25. The explanation of this structural break in the wage-population relationship is one of the most important purposes of the subsequent analysis.[6]

Data density is sufficient to construct annual series of real wages and population size back into the late seventeenth century. This renders it possible to implement a structural time series model of the wage-population relationship. For this purpose, we extend the real wage series to 1870 using data from Gömmel (1979), pp. 27-28. Given the tentative character of the population data before 1730 we present results separately for the two time periods 1690-1870 and 1730-1870.

The appropriate specification of a structural model of the relationship between real wages and population size depends of the properties of the two time series. In Table 2 we report results for the Augmented Dickey-Fuller test (ADF; null hypothesis: time series has a unit root) and the Kwiatkowski-Phillips-Schmidt-Shin test (KPSS; null hypothesis: time series is stationary) on the natural logs of both real wage series and population size. Since the wage series seem to display a structural break (cf. also Figure 1) we also provide the results of the Saikkonen & Lütkepohl (2002) unit root test (SL; null hypothesis: time series has a unit root) allowing for one endogenously determined breakpoint.[7]

With respect to the real wage series based on the extended dataset of silver wages deflated by the national CPI both the SL test with one break and the KPSS test suggest first difference stationarity. The ADF test with an intercept, by contrast, rejects a unit root. However, since this test may not be appropriate given the existence of a level shift in the series, we conclude that the real wage series based on the extended dataset is integrated of order 1 for both periods 1690-1870 and 1730-1870. The results are less clear for the series based on wages deflated by the respective local CPI in that only the KPSS test statistics unambiguously indicate w_t being I(1). However, since this series is based on fewer data, transitory local shocks assume greater weight in the data generating process. Because of this and because the KPSS test is generally regarded as more powerful than the ADF test it is reasonable to conclude that the true integration order of the real wage is I(1).

For population size the KPSS test suggests that the population size p_t is I(2) for the period 1730-1870 and I(1) for the time period 1690-1870, whereas the ADF test suggests first difference stationarity for both subperiods. The extrapolation of annual values before the 1730s rests on information from a rather small sample of parishes, however. This part of the series is therefore strongly influenced by local shocks unrelated to the underlying data generating process. For this reason we conclude that the true integration order of the population series is I(2).

In what follows we implement a structural time series model on the basis of the assumption that population is I(2) and wage is I(1). This conforms to results obtained for England with re-

[6]Alternative estimates were carried out with a time dummy assuming the value of 1 in the years after 1650 and zero otherwise. The interaction effects were weaker, with one estimate failing to reach statistical significance at the level of ten percent. The resulting values for the elasticity of the real wage on population are in the range of -0.3 to -0.35.

[7]JMulTi (www.jmulti.com) has been used to conduct the three tests.

Table 2: Unit root and stationarity test results

	test statistics		critical values			conclusion
	1690-1870	1730-1870	1%	5%	10%	
Panel A: ln real wages using national CPI						
ADF test						
intercept	−2.9565	−3.0516	−3.43	−2.86	−2.57	I(0)
intercept and trend	−2.9945	−3.0622	−3.96	−3.41	−3.13	I(1)
SL test with one break						
intercept, BP: 1852 (2lags)	−1.7024	−1.3768	−3.48	−2.88	−2.58	I(1)
intercept, BP: 1816 (0 lags)	−2.6905	−2.1413	−3.48	−2.88	−2.58	I(0), I(1)
intercept and trend, BP: 1852 (2 lags)	−1.8427	−2.0214	−3.55	−3.03	−2.76	I(1)
intercept and trend, BP: 1816 (0 lags)	−2.9265	−2.5176	−3.55	−3.03	−2.76	I(0), I(1)
KPSS test						
intercept	0.8728	0.4106	0.739	0.463	0.347	I(1)
intercept and trend	0.4453	0.4077	0.216	0.146	0.119	I(1)
Panel B: ln real wages using local CPI						
ADF test						
intercept	−4.2080	−3.7942	−3.43	−2.86	−2.57	I(0)
intercept and trend	−4.1999	−3.8720	−3.96	−3.41	−3.13	I(0)
SL test with one break, BP: 1943						
intercept	−2.8691	−2.1882	−3.48	−2.88	−2.58	I(0), I(1)
intercept and trend	−3.1155	−2.8131	−3.55	−3.03	−2.76	I(0)
KPSS test						
intercept	0.6332	0.4034	0.739	0.463	0.347	I(1)
intercept and trend	0.4077	0.3638	0.216	0.146	0.119	I(1)
Panel C: ln population and first differences						
ADF test						
level	−0.9044	−0.8873	−3.96	−3.41	−3.13	I(1)
1st difference	−7.9720	−7.1901	−3.43	−2.86	−2.57	I(0)
KPSS test						
level	0.6184	0.6767	0.216	0.146	0.119	I(1)
1st difference	0.3240	0.6206	0.739	0.463	0.347	I(0), I(1)

Note: The tests on the level of the ln wage rate w are conducted allowing for a nonzero intercept and allowing for both, nonzero intercept and trend term. In addition we allow for a breakpoint in the level conducting the Saikkonen and Lütkepohl (2002) test. The endogenously determined breakpoint (BP) depends on the chosen lag length (cut-off region). The test on the level of ln population p is conducted allowing for a nonzero intercept and a time trend. Δp is tested including a nonzero intercept only. The lag lengths for the ADF test and the SL test are chosen according to standard information criteria AIC, HQ and SC. The lag truncation parameter used in the KPSS test determined by $4(T/100)^{0.25}$ (lags for computing the long run variance).

spect to similar and earlier time periods (Lee & Anderson (2002), pp. 200-201, Crafts & Mills (2009), p. 82). A higher order of integration for population relative to the real wage is theoretically sound, i.e. consistent with Malthusian theory: As a cause of demographic adjustment through the preventive and the positive checks, the real wage fluctuates around a long-run equilibrium, whereas changes in the demand for labor cause population to follow a higher order process (Lee & Anderson (2002), pp. 200-201).

Hence, we specify a structural model of the relationship between the real wage and population size as follows (Lee & Anderson (2002), p. 205, Crafts & Mills (2009), p. 81-82; cf. also Fernihough (2010), pp. 20-22). Equation (3.1) contains a cointegrating relationship between α_t (the demand for labor) and p_t. Thus, in order for Eq. (3.1) to be balanced, and assuming that $p_t \sim$ I(2), α_t must be a process with integration order I(2) that is cointegrated with p_t. Therefore, we model α_t as a composition of its lagged value and a stochastic drift component:

$$\alpha_t = \alpha_{t-1} + g_t \tag{3.3}$$

$$g_t = g_{t-1} + \nu_t, \quad \nu_t \sim N(0, \sigma_\nu^2) \tag{3.4}$$

ν_t is a white noise random variable, whereas the drift, $g(t)$, captures changes in the demand for labor. Some authors have equated g_t with the rate of technological progress (Lee & Anderson (2002), p. 211, Crafts & Mills (2009), p. 85), but apart from technological progress changes in the demand for labor could also arise from increases in capital intensity, improvement of the efficiency of factor allocation due to market integration and regional specialization (Smithian growth) as well as from long-term changes of climatic conditions.

Following standard practice the disturbance term s_t in Eq. (3.1) is modelled as an AR(2) process:

$$s_t = \gamma_t s_{t-1} + \gamma_2 s_{t-2} + \varepsilon_t, \quad \varepsilon_t \sim N(0, \sigma_\varepsilon^2) \tag{3.5}$$

ε_t is again a white noise random variable, whereas γ_1 and γ_2 are parameters.

The parameters of equations (3.1) and (3.3)-(3.5) are estimated using the state space form of these equations. For this purpose, the model is rewritten in matrix notation to implement the Kalman filter. Before doing so, note that Eq. (3.3) describes just an identity. Thus, g_t does not have to be included in the filter and can be easily computed afterwards whereas α_t can be modelled as a two times integrated stochastic process rewriting Eqs. (3.3) and (3.4) using $g_{t-1} = \alpha_{t-1} - \alpha_{t-2}$ as follows:

$$\alpha_t = 2\alpha_{t-1} - \alpha_{t-2} + \nu_t, \quad \nu_t \sim N(0, \sigma_\nu^2) \tag{3.6}$$

In addition, as suggested by Durbin & Koopman (2001), pp. 121/122, the parameter β is included in the state vector such that in each period $t,\ t = 1, \ldots, T$ the observation equation is denoted by

$$y_t = H_t \theta_t$$

with $y_t = w_t$, $H_t = (1,\ 0,\ 1,\ 0,\ p_t)$ and $\theta_t = (\alpha_t,\ \alpha_{t-1},\ s_t,\ s_{t-1},\ \beta_t)'$ and the state equation becomes

$$\theta_t = F\theta_{t-1} + e_t$$

with $F = \begin{pmatrix} 2 & -1 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & \gamma_1 & \gamma_2 & 0 \\ 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 \end{pmatrix}$ and e_t being the vector of innovations $(\nu_t,\ 0,\ \varepsilon_t,\ 0,\ 0)'$. The error term vector e_t is multivariate normally distributed for which $\mathrm{E}[\nu_t \varepsilon_s] = 0\ \forall s, t$. As common in the literature, the AR(2) parameters γ_1 and γ_2 are restricted such that the state variable s_t is modelled as a stationary process, and the variances σ^2_ν and σ^2_ε are restricted to be positive.

A Kalman filter maximum likelihood procedure ist applied to obtain the filtered states and the parameter estimates using the BFGS-algorithm implemented in the GAUSS OPTMUM package (GAUSS 9.0). Coefficient standard errors are computed using numerical second order derivatives.[8] Table 3 presents the estimates for all parameters (including the filtered values for β) and the variances. The estimates for the periods 1690-1870 and 1730-1870 as well as those obtained for the two different real wage series are largely similar. Therefore, both the plots of α_t, g_t and s_t in Figure 5 and the later discussion of the results refer to the longer time period and the estimates obtained using the wage series based on the extended dataset of silver wages deflated by the national CPI. The estimates for γ_1 and γ_2 are consistent with the presumed stationarity of the error process s_t in that their sum is well below unity.

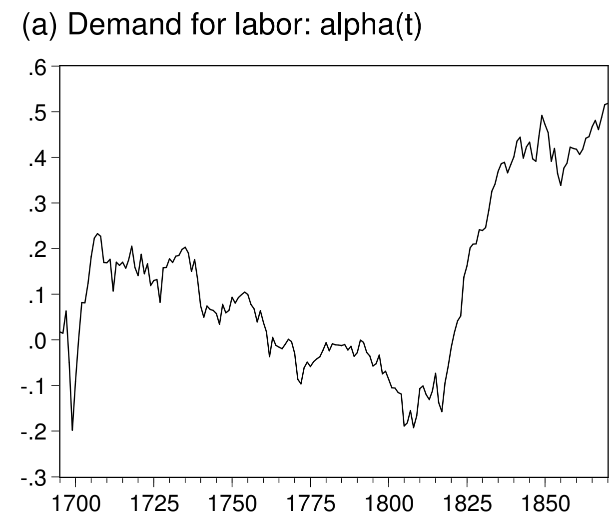
β converges to about -0.5.[9] Its absolute magnitude is lower than the estimate in Table 1 for the sixteenth century, which confirms the earlier impression of a weakening of the wage-population relationship after the middle of the seventeenth century. At the same time, the absolute magnitude of β is larger than the sum of the base and the interaction effects in Table 1 suggests for the post-1600 period (-0.15 to -0.35; cf. also footnote 6). We offer two explanations for this discrepancy: First, we shall argue below that the population-wage combination in 1650 represents a situation below equilibrium. Given the absence of other population estimates for the seventeenth century before 1690 this greatly flattens the linear wage-population relationship during the post-1600 era. Second, outward shifts of labor demand, which are captured by the state variable α_t in the structural time series model, translate into a flattening of the linear wage-population relationship. Both arguments lead us to conclude that the true value of β must have been around -0.5 and that the specification of equation (3.2) and the data underlying Table 1 underestimate the magnitude of β, at least from the late seventeenth century onwards.

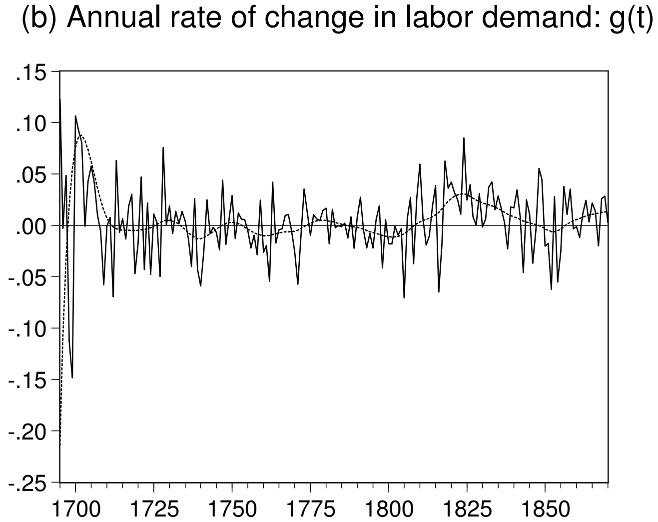
Because the tests presented in Table 2 do not unambiguously support the assumption of p_t being I(2) and $w_t \sim$ I(1) we conclude this section by exploring an alternative structural model of the relationship between population and real wage that is consistent with the assumption that p_t is only I(1) and that w_t is either stationary or is integrated at order I(1). A structural model that is consistent with these assumptions replaces equation (3.4) with the following specification:

$$g_t = \phi G(t, \xi, c) g_{t-1} + \nu_t, \quad \nu_t \sim N(0, \sigma^2_\nu) \tag{3.7}$$

[8] The programming code is available on request.

[9] Note that for β an initial value of $\beta_0 = -0.8$ was chosen on the basis of Table 1. Research on other countries, notably England and France, suggest the possibility of higher values of absolute magnitude for β. Therefore, we also used $\beta_0 = -1.46$ as corresponding starting value in the state vector (cf. Lee & Anderson (2002), p. 210). The coefficient estimates are almost identical. Results are available on request.





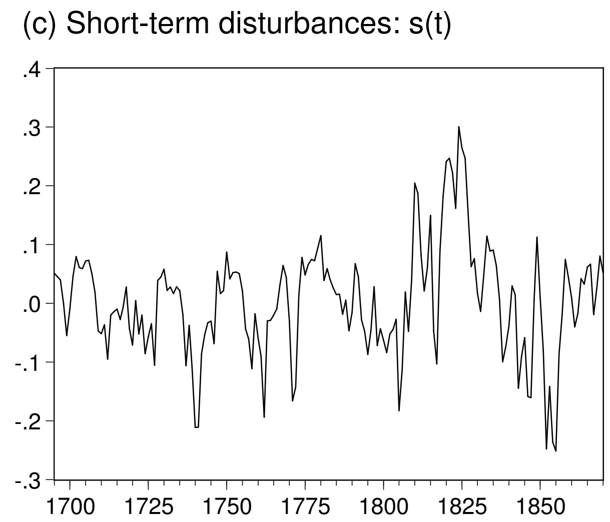


Figure 5: The filtered states α_t, the computed difference g_t and its smoothed values (dashed line in panel (b), HP-Filter with $\lambda = 100$), and s_t for the structural model presented in equations (3.1) and (3.3)-(3.5) and the corresponding estimation results reported in Table 3, column 1. Note that the first five observations are cut off (influence of initial state values).

Table 3: Estimates of coefficients and variances of structural model, 1690/1730-1870, equations (3.1) and (3.3)-(3.5)

		national CPI			local CPI	
	starting values	1690-1870	1730-1870	starting values	1690-1870	1730-1870
γ_1	1.2	0.8037	0.8343	1.2	0.7760	0.8196
		(0.0613)	(0.0362)		(0.0354)	(0.0623)
γ_2	$-0.4,\ -0.6$	-0.1178	-0.1182	-0.4	-0.0563	-0.0732
		(0.0505)	(0.0335)		(0.0168)	(0.0478)
σ_ε^2	2	0.00737	0.0078	2	0.0082	0.0084
		(0.0013)	(0.0011)		(0.0008)	(0.0011)
σ_ν^2	1	2.1293e-6	2.2765e-6	1	1.0449e-6	1.4496e-6
		(1.2940e-6)	(2.0829e-6)		(8.3360e-7)	(1.2940e-6)
β	-0.8	-0.4951	-0.4782	-0.8	-0.4867	-0.4761
$\ln L$		160.368	117.152		152.976	113.470

Note: Standard errors are given in parentheses. The entries for β are filtered values (last iteration, last observation). $\ln L$ denotes the value of the loglikelihood function. For national CPI data, the starting value for γ_2 differs between the subsamples due to complex standard errors obtained from numerical optimization.

with $G(t, \xi, c) = (1 + \exp(-\xi(t - c)))^{-1}$ being a logistic function that depends on a linear deterministic trend term variable t. Thus, the drift term is no longer modelled as a simple random walk but as a nonlinear process. The parameter c denotes a threshold value determined from the data. The parameter $\xi > 0$ (identification restriction) governs the speed of transition between two regimes. The smaller the estimate $\tilde{\xi}$, the smoother is the transition between regimes, whereas high values for ξ indicate an abrupt switch from one regime to another. Thus, the speed of transition is estimated from the data. This setup is more plausible than simply imposing a breakpoint at a certain point in time. However, note that the final parameter estimate for c depends on its chosen starting value. Thus, we estimated the state space model for different starting values and choose the one with the highest loglikelihood. The parameter ϕ is not restricted by boundaries and is robust to different starting values.

The parameter estimates are presented in Table 4.[10] Most notably, the estimate of β is unstable in that its value depends greatly from the specification of the period of observation: The absolute magnitude of the coefficient turns out much lower for 1690-1870 than for 1730-1870. We explain this with the fact that the alternative model treats the relative stability of the real wage in face of rapidly rising population during the first part of the eighteenth century as a disturbance rather than a systematic drift. Thus, the instability of $\tilde{\beta}$ *e contrario* testifies to the appropriateness of our preferred model (equations (3.1) and (3.3)-(3.5)). Even so, the filtered values of α_t produced

[10]Note that the implementation slightly differs from the one before. First, most obvious g_t now has to be included in the state vector θ_t. Second, due to computational aspects, g_t in Eq. (3.3) is replaced by g_{t-1} and, third, β is estimated and not included in the state vector (singularity problems). Since the filtered states and the parameter estimates do not depend on either way of the used matrix representation for our baseline model (Eqs. (3.1), (3.3)-(3.5)), we are well able to compare the results of both models with differing drift equations.

by the alternative model for the time period 1690-1870 suggest a trajectory quite comparable to Figure 5, panel (a): a modest increase at the beginning of the eighteenth century, a strong break during the early nineteenth century and renewed moderate rise thereafter.[11] The estimates for the other parameters are comparable to those in Table 3, although the AR(2) process is less persistent. The model produces a fit in terms of the loglikelihood that is comparable to the results of our preferred model in Table 3. We conclude that the results obtained from our preferred model in Table 3 and Figure 5 are robust, and the model is well specified.

Table 4: Estimation results for the state space model including a drift g_t via a logistic function allowing for one endogenous break, equations (3.1), (3.5) and (3.7)

		national CPI			local CPI	
	starting values	1690-1870	1730-1870	starting values	1690-1870	1730-1870
β	−0.8	−0.2623	−1.1138	−0.8	−0.4039	−1.0463
		(0.3758)	(0.2605)		(0.2110)	(0.2849)
γ_1	1.2	0.6887	0.7439	0.9	0.6803	0.7390
		(0.0836)	(0.0757)		(0.0775)	(0.1010)
γ_2	−0.4	−0.1970	−0.1886	−0.2	−0.1307	−0.1305
		(0.0527)	(0.0830)		(0.0551)	(0.0900)
σ^2_ε	2	0.0063	0.0070	2	0.0073	0.0076
		(0.0008)	(0.0009)		(0.0008)	(0.0010)
σ^2_ν	1	0.0002	5.3873e-5	1	6.1982e-5	4.0272e-5
		(0.0003)	(4.7156e-5)		(5.9814e-5)	(3.8670e-5)
ϕ	1	0.7177	0.9461	1	0.8885	0.9520
		(0.2548)	(0.0634)		(0.0990)	(0.0605)
ξ	4	25.2200	26.0211	4	17.6508	22.6061
c	100, 80	102.5122	76.5162	100, 80	96.4714	74.4443
$\ln L$		176.743	132.391		169.058	127.763

Note: Standard errors are given in parentheses. $\ln L$ denotes the value of the loglikelihood function.

4 Interpretation

Taken together, the information produced by this study so far lends itself to the following four statements concerning the evolution of the real wage and economic development in Germany from the sixteenth to the nineteenth centuries:

First, the sixteenth century was characterized by a dramatic decline of the real wage by about 40 to 43 percent between 1503-1507 and 1598-1602, which was only definitively reversed in the 1880s, when the German economy embarked on a path of rapid aggregate growth (cf. Figure 1). The decline started from 1508-1513 and minima were reached in 1593-1597, 1608-1612 and 1618-1622; given the imprecision of the estimates for the latter two five year periods it is impossible to

[11]Detailed figures of the filtered states are not presented to conserve space, but are available on request.

determine exactly when the downward movement ended. The first five year period corresponds to the general European crisis of the 1590s (Clark (1985)), the second and the third relate to the culmination of the *Kipper und Wipper* era and the onset of the Thirty Years' War (Kindleberger (1991)). The secular reduction of living standards was a common European phenomenon, but its extent may have been more drastic in Germany than elsewhere (Allen (2001), p. 428). It is noteworthy that a significant portion of the decline occurred already during the first part of the century; between 1503-1507 and 1527-1532 the real wage fell between a fifth and a third, depending on the real wage series one uses. This fact sheds new light on the background of the widespread social unrest during this period, which culminated in the Peasant War of 1525. The existence of a fairly close negative relationship between the real wage and population size during the sixteenth century suggests the prevalence of a static aggregate production function. Given the absence of significant technological progress and a declining marginal product of labor, 1 percent population growth translated into a decline of the real wage by an almost equal proportion (cf. Table 1, base effect of population size β). The fact that population grew unabatedly despite a strong decline of the real wage suggests that Malthusian checks were weak or nonexistent. Finally, earlier studies have drawn a link between the deterioration of climatic conditions from the late 1560s and the spread of mass poverty and social dislocation in late sixteenth-century Germany (Ch. Pfister & Brázdil (1999), Behringer (2005)). The existence of a stable elasticity of the real wage on population size during the whole sixteenth century on the contrary implies that the deterioration of material living conditions towards the end of the sixteenth century was primarily a Malthusian phenomenon and that climatic factors had at best a secondary impact on material welfare.

The second statement refers to the effects of the Thirty Years' War (1618-1648). From 1598-1603 to 1648-1652 the real wage rose by some 40 percent. The mean of 1653-1672, which marked the heyday of lower class living standards during the three centuries preceding industrialization, was about another 23 percent higher (with a wide margin of error); it stood some 73 percent above the level in 1598-1602 and was roughly equal to the value prevailing at the beginning of the sixteenth century. Since between 1600 and 1650 the combination of the real wage and population size moves upwards left along the regression line in Figure 4 it was not technological progress which lay behind this spectacular improvement of material welfare among wage earners, at least until 1650. Rather, the rise of the real wage during the first half of the seventeenth century was entirely due to the huge population losses (40 percent or more) during this time, most of them being the result of devastating epidemics of bubonic plague whose spread was facilitated by war-related geographical mobility. This result is noteworthy in a comparative context, since England experienced the first positive divergence of the real wage from the level predicted by population size during the 1640s (Clark (2005), p. 1312).

If we assume that the elasticity of the real wage on population prevailing in the sixteenth century applies to seventeenth-century conditions as well, we can make a rough estimate of the real wage that would have obtained with the reduced level of population of 1650 and thus assess the welfare implications of the Thirty Years' War. The outcome depends heavily on the real wage series used: In the case of wages deflated by the national CPI (column (3) in Table 1) the real wage prevailing in 1650 was only 4.6 percent below the predicted value. On the basis of wages deflated by the respective local CPI we get a difference of -15.4 percent, whereas the deviation between observed and estimated values amounts to -21.7 percent if we do not adjust locally deflated wages for changes in consumption patterns during the sixteenth century (basis: column (1) in Table 1). This difference of 5-22 percent constitutes a rough estimate of the war-related welfare loss net of the fall in population size: Given a static technology, the war benefitted its survivors through a strong rise of the marginal product of labor, but on the basis of the reduction of population size alone, the real wage should have been above the observed level.

Of course, we can only speculate about the nature of a probable war-related welfare loss net of population decline (cf. Stier & von Hippel (1996), pp. 240-243): Many regions suffered a decline of their capital stock that surpassed the reduction of the workforce as a result of plundering by marauding troops, particularly with respect to the size of cattle herds and seed stocks. In addition, local networks of production were disrupted by the dislocation caused by war-related mobility and high mortality rates in the wake of epidemics.

The assessment of the size of the war-related welfare loss crucially bears on the interpretation of the positive income shock occurring during the 1650s. If it was small, as suggested by Figure 4 and in column (3) of Table 1, then the wage increase of the 1650s must have been due to some exogenous force. A possible candidate is the integration into the emerging North Sea trading system that experienced a strong boost at this time given virtually unchallenged Dutch trade hegemony (Israel (1989), ch. 6, Ormrod (2003)). By contrast, if the existence of a war-related welfare loss is admitted, there is room for post-war reconstruction. If the net welfare loss is put at 22 percent the real wage increase between 1648-1652 and the average in 1658-1672 (23 percent) resulted entirely from reconstruction taking place in the first decade after the conclusion of peace. Given the crudeness of the presently available information it is impossible both to assess the share of post-war reconstruction in the income shock of the 1650s and to identify a possible exogenous source of income growth during this period.

The third group of observations relates to the period from the third quarter of the seventeenth to the late eighteenth century. After reaching a maximum around 1670 the real wage again entered into gradual decline. Considering the parallel growth in population size, which by 1740 reached the level attained in 1600, the fall of the real wage was moderate compared to the sixteenth century. This fact is expressed by a rather flat relationship between the real wage and population size after 1650 (Figure 4). Our structural model of the relationship between population size and the real wage for the period 1690-1870 suggests that the elastisticity of the real wage on population was only about -0.5 (compared to -0.74 to -1.02 during the sixteenth century; cf. Tables 1 and 3). In addition, the decline of the real wage was temporarily halted by a notable increase of labor demand at the beginning of the eighteenth century (Figure 5, panels (a) and (b)).

There are three partly related explanations of the flattening of the wage-population relationship and the temporary outward movement of labor demand, namely, market integration and proto-industrialization, human capital accumulation, and climatic change. First, many regions in Germany began to develop export-oriented handicraft industries from the second half of the seventeenth century (Kaufhold (1986), Ogilvie (1996)). This was also the era when the Second Commercial Revolution reduced trade costs and facilitated the integration of regional economies into international markets. The growth of non-agricultural employment in turn necessitated the development of systematic surplus production in agricultural regions and the development of grain markets. In fact, ongoing research on grain prices suggests that the dispersion of rye prices among fifteen German towns decreased between the second half of the seventeenth century and c. 1750 (Uebele, Pfister & Albers (2011)). The development of non-agricultural employment made possible by market integration rendered the economy less dependent on limited land resources with the consequence that the marginal product of labor fell less steeply as a result of population growth than before.

Second, it is striking to see that, in analogy to England during the seventeenth century, the relaxation of the negative link between real wages and population was accompanied by human capital accumulation in the form of a rapid rise of literacy and numeracy during the century following the Thirty Years' War, at least in the Protestant territories (Clark (2005), p. 1315; A'Hearn, Baten & Crayen (2009), pp. 801-802). It may well be that this provided basic skills that facilitated every-day interaction with markets (cf. Konersmann (2005)) and thereby contributed to making the German economy less dependent on local agriculture, where the marginal product of labor fell steeply.

Third, climatic change may have contributed to the increase of labor demand at the beginning of the eighteenth century. In fact, because of the temporary character of the outward shift of labor demand it is doubtful whether proto-industrialization related to market integration and human capital accumulation promoted genuine productivity growth beyond a mitigation of the negative wage-population relationship. By contrast, the end of the so-called Little Ice Age around 1700 produced a positive shock to agricultural output. Both tree-ring series and temperature reconstructions suggest that conditions for plant growth were on average more favorable and less subject to violent climatic shocks in the first three decades of the eighteenth century than during the second half of the seventeenth century (Briffa, Jones, Schweingruber & Osborn (1998), p. 451; Glaser & Riehmann (2009), pp. 445, 447). Improved conditions for plant growth increased the demand for harvest workers and threshers; rising incomes of land owners resulted in an expansion of the demand for manufactures and, hence, in a growth of employment in trade and manufacturing. The relevance of external shocks affecting a wider geographical area in the form of climate anomalies and war (see below) is highlighted by the fact that Germany and England display broadly similar trajectories of the rate of change of the demand for labor between the 1690s and the 1760s (cf. Figure 5 with Crafts & Mills (2009), p. 85).

Between c. 1740 and the early 1800s labor demand followed a negative trend. This implied divergence relative to England, where labor demand experienced a sustained rise from the 1760s. In the German case, a number of transitory shocks were related to unfavorable weather (cf. Figure 5, panel (c)): Harvest failures occurred particularly in 1740 (Post (1985)), 1758, 1762, 1771/72, 1795 (cf. Pfister & Fertig (2010), pp. 31, 33) and as a result of the eruption of the Tambora volcano (1815) in 1817 (Post (1977); Bass (1991), pp. 45-46, 128-177). The presence of some of these shocks in the state variable α_t representing labor demand suggests that they were aggravated by war-related structural shocks (Figure 5, panels (a) and (b)): The War of Austrian succession (1740-1748), the Seven Years' War (1756-1763) and the Revolutionary and Napoleonic Wars (1792-1815), which all led to severe economic and social dislocation (cf. O'Rourke (2006), Planert (2007), pp. 125-335), constituted periods of decline in labor productivity. Both transitory and war-related structural shocks were followed by at best weak recovery, however, which resulted in a downward trend of the level of labor productivity (Figure 5, panel (a)). The most proximate explanation again refers to climatic conditions: Frequent violent precipitation led to land erosion (Bork, Bork, Dalchow, Faust, Piorr & Schatz (1998), pp. 253-271), and winter temperature fell sharply (Glaser & Riehmann (2009), pp. 447). Both phenoma had evidently negative consequences for labor productivity and demand.

The apparent decline in labor productivity during the second half of the eighteenth century contrasts with a first boost in urbanization: From 1500 to 1750 the urbanization rate of Germany fluctuated between 7.1 and 9.2 percent, but rose to 11.3 percent in 1800 (Pfister (2011), p. 5). Given the absence of significant imports of grain, it is difficult to see how a growing urban share of the population could be fed without steeply rising relative prices of foodstuffs. Two arguments can reconcile the decline of labor productivity with the rise in urbanization: First, if one presumes a backward bending labor supply schedule with a wage elasticity of the per capita labor input in the order of magnitude of -0.3 (cf. Voth (2000), p. 180), the decline of the real wage between 1748-1752 and 1798-1802 by some 30 percent implies an increase of the per capita input of labor by about 10 percent. Likewise, the widespread reduction of feast days in Catholic territories during this period led to an increase of potential annual working time by 30 to 50 days (Hersche (2006), vol. 1, pp. 618-628). A genuine "industrious revolution" (de Vries (2008)) in terms of a shift of preferences from leisure to consumption and labor resulting from the increased availability of tropical groceries and textile populuxe goods may have further contributed to a rise in the per capita labor input. All this seems to have led to a substitution of land by labor and to have limited the rise of the relative price of foodstuffs (Uebele et al. (2011)).

Second, the decline of the marginal return to labor in agriculture produced by erosion heightened the productivity gap between town and countryside and encouraged structural change. In sum, while adverse shocks and environmental degradation certainly exerted a negative impact on the development of labor productivity during the second half of the eighteenth century they did not erase the dynamic gains from market integration that had occurred during the first part of the eighteenth century.

The fourth and last group of observations refers to the period from the late 1810s. An outstanding result of Figure 5 is the extreme positive shock that labor demand experienced around 1820. While its exact size depends somewhat on the consequences one attributes to the rampant energy crisis for the level of consumer prices (cf. section 2 above), its importance as a turning point in German economic history is underlined by the contemporaneous disappearance of the positive check of the real wage on the death rate as well as a marked decline of inter-urban rye price dispersion during the late 1810s (Pfister & Fertig (2010), pp. 31, 41-50; Uebele et al. (2011); cf. also Uebele (2011), p. 188).

Three explanations of the very strong growth in labor demand stand out, namely, climatic change, post-war reconstruction, and institutional change favoring market integration. First, climate seems again have played an important role. Temperature reconstructions and tree-ring series show exceptionally good conditions for plant growth during the 1820s, which must have boosted labor demand (Briffa et al. (1998), p. 451; Glaser & Riehmann (2009), p. 442). Second, the strong dislocations that Germany suffered from the Revolutionary and Napoleonic Wars created room for post-war reconstruction. If we take the level of the real wage (Figure 1) and of labor demand (Figure 5, panel (a)) during the early 1790s as a benchmark, however, reconstruction was already completed by 1820 in that both variables reached their pre-war level around this time. The importance of climate and post-war reconstruction are underlined by the observation of a contemporaneous peak of labor demand growth in England (Crafts & Mills (2009), p. 85).

Both favorable weather and post-war reconstruction were temporary phenomena. Nevertheless, panels (a) and (b) of Figure 5 demonstrate that apart from a temporary break around 1850 a positive mid-term growth of labor demand could be maintained beyond the 1820s. It was accompanied, however, by a shift from strongy positive to strongly negative transitory shocks between the late 1820s and the 1840s (cf. Figure 5, panel (c)). The opposing development of short-term and mid-term movements of labor demand can reconcile our optimistic assessment of economic development during the early nineteenth century with contemporary concern about widespread pauperism (Wehler (1987), pp. 281-296).

Thus, the sustained character of the increase of labor demand occurring from c. 1820 suggests, third, a positive effect of institutional change. Reforms affecting the commercial sector seem to have been more important than those relating to agriculture. Agrarian reforms began to be enacted during the first quarter of the nineteenth century, but their full implementation had to await the 1840s and 1850s in most German states (Dipper (1980), ch. 2). Thus, the increase of labor demand clearly ante-dates not only industrialization but also institutional change in agriculture. The strong decline of inter-urban grain price disparities points to a decisive advance of market integration during the early years after the Napoleonic Wars. Tariff and monetary reforms in the larger German states, a liberalization of commercial law that lowered access barriers to business and state programs of road construction can be invoked as contributing factors (Borchard (1968), pp. 260-78, Otto (2002), pp. 28-99). In contrast to the late seventeenth and early eighteenth centuries the dynamic of market integration now went beyond mitigating the fall of the marginal product of labor and led to a sustained productivity increase.

The onset of a sustained growth of labour productivity around 1820 also has implications for the interpretation of the consequences of early industrialization on economic growth. Conventional wisdom suggests that Germany experienced a Rostowian take-off into industrial growth from the 1840s or 1850s to the early 1870s (Rostow (1956), p. 31, see Sarferaz & Uebele (2009), pp. 370, 385 for further discussion). By contrast, we find that sustained growth began already well before industrialization and that there was no increase in labor demand growth during the 1840s and 1850s (Figure 5, panels (a) and (b)). In a competitive labor market the wage equates the marginal product of labor, and under a Cobb-Douglas production function the marginal product of labor is equal to the average output of labor times the labor share in national income. Thus, there exists a linear relationship between changes in the real wage and per capita output growth. During the period 1851-1870 the real wage increased by 13.6 percent, the demand for labor (α_t) by 4.7 percent and per capita income estimated on the basis of tax returns by 6.6 percent. The widely used national output estimate by contrast records a massive increase of 26.0 percent on a per capita basis during the same period (Burhop & Wolff (2005), pp. 633-638, 651; population from Kraus (1980), p. 338). Our findings thus support the view that the German economy grew slower during the 1850s and 1860s and that the true level of economic activity around 1850 was on a higher level than suggested by the output series (see also Fremdling (1995), pp. 82-84). Contrary to a

Rostowian perspective on the Industrial Revolution, economic growth accelerated little with the onset of industrialization and remained on a modest level during its first phase, although severe negative shocks leveled out after c. 1855. This is compatible with the Crafts-Harley view of the British Industrial Revolution (Crafts & Harley (1992), Harley (1999)): Leading sectors, despite their rapid growth (cf. Fremdling (1985), p. 21), were too small initially to have a major impact on economic growth, and expanding world markets for manufactures diluted the gains from domestic productivity growth to foreign consumers through a decline in the terms of trade.

5 Conclusion

Drawing on new data series for prices, wages and population, the present investigation into the long-term trajectory of the real wage in Germany joins in a larger literature that sees major processes of divergence with respect to income levels and economic growth occurring well ahead of the onset of industrialization (Allen (2001), Broadberry & Gupta (2006)). First, we find that a sustained growth of labor productivity began in the late 1810s and that only a modest acceleration took place with the onset of industrialization in the late 1840s and 1850s. Thus, the Crafts-Harley view of the Industrial Revolution applies to the German case as well. Second, our evidence suggests a departure from a situation in which technological stasis implied a strong negative effect of population growth on levels of material welfare some time during the second half of the seventeenth and early eighteenth centuries. Growing market integration, possibly aided by human capital accumulation, mitigated the fall of the marginal product of labor resulting from the limited availability of land, and the end of the Little Ice Age contributed to a temporary increase of labor demand and productivity at the beginning of the eighteenth century. Our results suggest an important role for Smithian growth in long-term development: Market integration promoted regional specialization as well as the growth of the urban economy. As a dynamic effect, this facilitated the emergence and the spread of technological innovations, which in turn provided a fertile ground for the transition to industrialization and modern growth.

To conclude, we stress the tentative and provisional character of our work. Particularly with respect to the period up to the third quarter of the seventeenth century our data base is tenuous, and the margin of error of several results remains wide. Given our present knowledge of sources, gaps are difficult to close for this early period, however. Things stand differently for the nineteenth century, particularly the period before state offices systematically began to collect price information (Broadberry & Burhop (2010)). Our consumer price data are actually less dense for the early nineteenth than the eighteenth century, and we have shown that the assessment of real wage movements during the early nineteenth century strongly depends on the consumer price index that is used. Exploring hitherto unused information about consumer prices, therefore, has a high potential to expand our knowledge regarding the timing and pattern of Germany's transition into modern growth.

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