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ORIGINAL PAPER

Malthus in preindustrial Northern Italy?

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Abstract
The Malthusian model, which implies a long-run interaction between demography and living standards, forms a cornerstone of our understanding of comparative economic development, as postulated by unified growth theory. Its empirical validity has been supported by a number of studies, most of which examine England. In Northern Italy, however, there might have been a reversed "preventive check." We employ a cointegrated VAR model on Italian data from ca. 1650–1799 and find some evidence for this, but also for diminishing returns and thus a more "Malthusian" society than in, for example, England at that time.

Keywords Cointegration · Italy · Malthusian · Post-Malthusian

JEL codes J1 · N33 · O4

1 Introduction

The overarching theoretical framework for understanding the transition from stagnation to growth and the differential timing of this, as well as the role played by demography, is unified growth theory (UGT). Within this, the literature has suggested an interaction

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between human evolution and economic development and can be divided into two strands (see also the survey by Ashraf and Galor 2018). The first explains that the greater fertility of more economically successful individuals, which follows naturally from the Malthusian preventive check, led to a gradual increase in their share of the population. Such success might be due to innate (genetic) preferences for the quality rather than quantity of offspring, resistance to infectious diseases, human body size, time preference, and more (see Galor and Moav 2002, 2007; Lägerlof 2007; Galor and Özak 2016).[1] The second strand considers the effect of the prehistoric movement of anatomically modern humans from Africa on the genetic composition of societies, as in Ashraf and Galor (2013). Their focus is on the impact on contemporary development, although they also suggest that, following Malthus, there would also have been an impact on population density in preindustrial times, a hypothesis confirmed by Ashraf and Galor (2011).

Given the importance of the Malthusian model for understanding comparative development, it is perhaps no surprise that recent years have witnessed something of a boom in studies attempting to test the hypothesis of a "Malthusian" preindustrial world, a concept central to UGT (see Galor 2011). Such a world should be characterized by three relationships: (1) the preventive check, whereby fertility increases with income (possibly through marriages becoming more frequent at higher levels of income); (2) the positive check, whereby mortality varies inversely with income; and (3) diminishing returns to labor, i.e., the fall in income when the workforce/population increases, due to the existence of fixed factors of production, land in particular. Together, these relationships anticipate a stable "subsistence" level of income, whereby any increase in productivity and thereby income is wiped out by a resultant increase in population and the onset of diminishing returns. UGT posits that the third relationship should break down at some point, giving rise to a "post-Malthusian regime," which will eventually be superseded by a complete collapse of the Malthusian model as countries undergo the demographic transition and move into the world of modern economic growth. In the present work, we test whether the experience of Northern Italy fits into this theoretical framework. We find some evidence that this was the case, but also that the preventive check appears to be reversed: higher real wages led to lower levels of fertility.

The rest of the paper is organized as follows. The following section presents a review of the literature, and Section 3 presents the Malthusian model. Section 4 presents the data and the historical context. Section 5 presents our econometric framework and the analysis, while Section 6 provides an interpretation of the results. Finally, Section 7 concludes.

2 Review of the literature

A large number of studies have looked for evidence of Malthusian mechanisms in preindustrial societies, mostly England, such as Bailey and Chambers (1993), Lee and Anderson (2002), Nicolini (2007), Crafts and Mills (2009), Klemp (2012), and Møller and Sharp (2014). The first four papers studied the Malthusian dynamics using a variety

[1] The seminal contribution by Galor and Moav (2002) was later tested by Galor and Klemp (2019) using historical population registers from Quebec, which offer convincing evidence for changes in preferences regarding quality and quality of children.

of econometric techniques, while the latter two introduced a novel approach, namely the cointegrated VAR model. Møller and Sharp combined the cointegrated VAR model with data on real wages as well as birth, death and marriage rates, and a sound theoretical basis, to provide a way for testing for the post-Malthusian regime, and finding support for this from the sixteenth century until the late eighteenth century. Apart from including the potentially important marriage rate into the econometric framework, the cointegration approach has the advantage that it can be interpreted as looking for long-run equilibrium relationships in the data and is able to test directly for a post-Malthusian regime. Outside the UK, Klemp and Møller (2016) apply a similar approach (although not using marriage rates) to Scandinavian data, finding results similar to those for England. Murphy (2010) also uses the cointegrated VAR model to study preindustrial France. His results are slightly different, since he does not find that France was in a post-Malthusian regime. However, he finds that in equilibrium, the birth and death rates equilibrate.[2]

Here, we take up the example of Northern Italy, again, applying Møller and Sharp's methodology. Apart from the obvious point that we thus look for evidence of the (post-) Malthusian model in another setting, there are additional reasons to believe that Northern Italy might be an interesting case study. In particular, the first to consider this question, Chiarini (2007, 2010), found evidence that this region might have displayed some striking peculiarities, with important implications for the economic literature on long-run comparative development as outlined above. Specifically, Chiarini, using long time series from the thirteenth to the nineteenth century, considered the relationship between real rural wages and population (but not individual series for births, marriages and deaths) in Italy using a cointegrated VAR setting. He finds a strong and significant positive check and diminishing returns, consistent with the pure Malthusian model. Curiously, however, he finds no evidence for a preventive check: in fact, he finds a *negative* feedback from wages to population.

Chiarini (2010) suggests that an old age security motive can explain his finding of evidence for a negative relationship between family income and fertility. Children can be viewed as a capital good, enabling transfers from their parents' productive age to their old age. If alternative capital goods exist (such as new seeds, better soybean quality, new irrigation, and cultivation methods), the parents will only invest in children if they believe they will yield a higher return than investment in other capital goods. By using an overlapping generations model that allows for substitution between the quantity of children and other assets, he demonstrates how the wage-fertility relationship can become negative. Finally, he also suggests that in a setting where usable land is not increasing, combined with a multitude of infectious diseases causing high mortality rates (and very high infant mortality rates), wages are likely to increase (the positive check). However, because of the high risks of disease, marriages, and consequently procreation, might be postponed to better times where the risk is smaller. This explanation fits well in the context of Northern Italy, where bad weather caused a series of bad harvests and famine, ultimately bringing about diseases and epidemics to the population.

[2] Klemp (2012) built on an earlier working paper by Møller and Sharp, which was published in 2014. He introduced a two-sector model which allowed for the inclusion of a potential price effect on fertility as postulated by the unified growth theory of Strulik and Weisdorf (2008), who argue that the price of children (captured by the price of food) relative to other goods is key to understanding fertility decisions. He finds no evidence that this was the case for England, however.

Although Chiarini's ideas have little real implications for the UGT literature, since only the positive or preventive checks are necessary to support a Malthusian interpretation of the economy, we argue that this deserves more consideration, especially since he lacked the data which can be used to perform a full test of the model. Moreover, more recent work by Fernihough (2013) finds evidence of both the checks and diminishing returns to labor, but fails to incorporate data on the marriage rate, which is necessary for a full test of the preventive check (although again not important for UGT itself). Moreover, we argue that his stationary VAR approach cannot address issues of non-stationarity in the data, while his state-space model is less standard than the cointegrated VAR approach suggested by Møller and Sharp (2014).

We thus suggest that the appropriate framework for resolving this debate is to apply the statistical framework proposed by Møller and Sharp (2014), which is in turn built upon work by Møller (2008). This has the obvious advantage that our results are directly comparable with Møller and Sharp (2014), as well as with those of Klemp and Møller (2016) and Murphy (2010). We focus on the period from the mid-seventeenth century until the turn of the nineteenth century and, consistent with the work of Chiarini, we find evidence of a negative relationship between the marriage rate and real wages. We thus contribute to the existing literature by demonstrating that Italy displayed some different dynamics that cannot be explained in the same setting as other countries already studied, possibly because of a different set of social norms and economic performance. Moreover, although Italy led the Renaissance in the fifteenth and sixteenth century, we find that it was a purely Malthusian society, in contrast to England, which had already progressed to the post-Malthusian regime.

3 The Malthusian model

In order to provide the theoretical background to our empirical results, this section presents a simplified version of the model of Malthusian stagnation as laid out by Møller and Sharp (2014). We first present the model without nuptiality, and then we explain how marriages can be included. The model considers a small, closed economy where the population size is endogenous. One homogenous good is produced using fixed land and labor as inputs. The income of each worker is represented by the real wage, and labor is supplied inelastically at the market clearing wage in the aggregate labor market. Production is assumed to follow a constant-returns-to-scale Cobb-Douglas function. The following system of equations describe the Malthusian mechanisms:

$$w_t = c_0 - c_1 \ln N_t + \ln A_t \tag{1}$$

$$b_t = a_0 + a_1 w_t + \varepsilon_{\mathrm{bt}} \tag{2}$$

$$d_t = a_2 - a_3 w_t + \varepsilon_{\mathrm{dt}} \tag{3}$$

$$\ln A_t = \ln A_{t-1} + \varepsilon_{At} \tag{4}$$

$$\ln N_t \equiv \ln N_{t-1} + b_{t-1} - d_{t-1} \tag{5}$$

where w_t is the natural logarithm of the real wage, b_t is the crude birth rate, d_t is the crude death rate, and N_t is the total population all at time t. A_t is an expression for the aggregate level of technology. It is thus assumed that technology accounts for all changes in productivity, even though of course other non-technological factors such as institutions would also play a role. The parameters of the model are all positive and the error terms are stochastic and normally distributed with zero mean and constant variances. The shocks to the demographic variables, $\varepsilon_{\mathrm{bt}}$ and $\varepsilon_{\mathrm{dt}}$, represent unmodeled unsystematic influences on births and deaths such as war, epidemics, and political disintegration.

Equation 1 is the wage expression and shows how real wages are affected negatively when the population/workforce increases. When the level of technology changes, the level of real wages changes as well. The parameter $c_1 > 0$ expresses the diminishing returns to labor. Equations 2 and 3 describe the preventive and positive checks respectively. The fact that the parameters a_1, $a_3 > 0$ indicates that the birth rate is affected positively by the real wage, while the death rate is affected negatively. In the literature, the explanations for the preventive check are multiple, while the positive check can be explained by purely biological circumstances given the adverse effects of lower income on nutrition and mortality. There is some evidence that the preventive check, apart from being biologically determined, is a result of rational economic behavior of couples in terms of birth spacing and expected infant mortality; see for example Cinnirella et al. (2017) for preindustrial England and Ejrnæs and Persson (2014) for a study on Italy. As shown in what follows, birth rates can also be explained by the number of marriages. Technology is expressed by Eq. 4 where it clearly follows a random walk process. This is an important assumption in the econometric framework. Finally, Eq. 5 shows the dynamics of population growth. In the model, the effects of external migration are ignored, and population growth is thus given by the difference between the birth and the death rates. The assumption of no external migration seems acceptable as it has been suggested that the effects of migration in Northern Italy were insignificant until the second half of the nineteenth century (see Galloway 1994).[3] The evolution of the labor force is here assumed to be proportional to the total population. This is an assumption we make to simplify the model, but it is possible to imagine that improvements in mortality were not equally distributed across ages.

Solving the system of equations with respect to $\{w_t, N_t, A_t, b_t, d_t\}$ yields the short-run equilibrium. The steady state values can be found from the solution when population growth is zero, no shocks are present, and technology is held fixed. The resulting level

[3] The insignificance of migration is discussed in Galloway (1994) where the same assumption has been made for the construction of vital and nuptiality rates. Based on both social and economic indicators, Galloway suggests that migration both within Northern Italy and outside Italy was not important until the second half on the nineteenth century (around the unification of Italy in 1861).

of real wages is the subsistence level. The conditions for the existence of a steady state can be found in Møller and Sharp (2014).

Following Møller and Sharp, an augmented model including nuptiality can be defined by assuming that the preventive check works through marriages. This can be modeled by separating the preventive check into one part explaining the birth rate and another explaining the marriage rate. Births are modeled as a linear approximation around steady state values (m^*, b^*, d^*), with $b^* = d^*$. It is assumed the marriage rate, m_t, depends on future expected income and the relationship is derived under the assumption of adaptive expectations. The augmented model replaces Eq. 2 with the following two equations describing the preventive check:

$$\begin{aligned} b_t \simeq e_0 + e_1 b_{t-1} - e_1 d_{t-1} + f_1 m_{t-1} + e_2 b_{t-2} - e_2 d_{t-2} + f_2 m_{t-2} + \\ + \ldots + e_s b_{t-s} - e_s d_{t-s} + f_s m_{t-s} + \varepsilon_{bt} \end{aligned} \tag{6}$$

$$m_t = a_4 + a_5 w_t + \varepsilon_{mt} \tag{7}$$

Equation 6 describes the birth-marriage part of the preventive check and Eq. 7 describes the marriage-income part. As in the simple model, it is possible to derive both the short-run equilibrium and the steady state values.

The empirical analysis will be based on the augmented model, a choice supported both by the emphasis Malthus put on the marriage-based explanation of the preventive check, and because empirically including marriages improves the statistical specification of the birth rate equation. In the presence of Malthusian stagnation, the level of technology is assumed to be exogenous following a random walk. However, the empirical framework is constructed to test for the presence of post-Malthusian mechanisms. The post-Malthusian hypothesis posits that the diminishing returns to labor are no longer present in the standard model presented above while it is still possible to have the positive and preventive checks.

4 Data and context

Our analysis relies on four data series, comparable to those for England used by Møller and Sharp (2014). The sources are the same as those used by Fernihough (2013), although we focus on a shorter period, and also introduce the crude marriage rate along with the birth and death rates. The demographic series come from Galloway (1994) and give annual observations of crude birth, marriage, and death rates (per thousand head of population). The real wage data (here given in logarithms) were collected by Paolo Malanima and represent average daily wages covering both rural and urban areas.[4] For the urban wages, masons have been used and the rural wages represent laborers. As a robustness check, we also use the inverse of wheat prices and perform the analysis

[4] Available online: http://www.paolomalanima.it/default_file/Italian%20Economy/Wages_Italy_1290_1990.pdf

using two distinct measures of real wages: agricultural wages and urban wages. These checks, however, make little difference to our conclusions.[5]

The demographic series cover an area labeled "Northern Italy" including the five regions: Lombardy, Piedmont, Tuscany, Veneto, and Emilia-Romagna. Data on the wage rate originate from the regions of Tuscany for the urban wages and Lombardy/Tuscany for the rural wages. A concern regarding the real wages is that they might not be representative for the whole area labeled "Northern Italy." However, the urban wages of Tuscany are highly correlated with comparable wages for the other regions, and the rural wages are assumed to be similar to the rest of Northern Italy, as evidence suggests that changes in conditions of the laborers were similar in the various regions (Federico and Malanima 2004).[6] Furthermore, we use the real wages covering both urban and rural areas in our main analysis because of the expansion of the urban economy that caused relative urban wages to rise during the sixteenth century. Thus, using only the urban wages would bias the results. Before 1861, the Italian regions were under different governments and thus studying separately the different regions (because of lack of demographic series for the south and a wage rate covering the entire peninsula) does not create any issues. In fact, it can be argued that there might be important differences between north and south (see Ejrnæs and Persson 2014), justifying a focus on Northern Italy alone.[7]

As in the rest of Europe, urban wages in Northern Italy increased after the Black Death, and the level remained relatively high for about a century. Around 1500, Northern Italy was the most advanced European region together with the Netherlands. Wages started decreasing during the second half of the fifteenth century and reached a minimum after 1530. Thereafter, the position of Northern Italy in the European hierarchy weakened. In the early seventeenth century, shortly before our complete dataset starts, the Netherlands were already much wealthier than Italy, while Spain also enjoyed a higher level of per capita GDP. Therefore, the economic dominance that Italy had enjoyed during the renaissance was gone at the time at which our analysis starts. Figure 1 graphs GDP per capita for Italy, England, the Netherlands, and Sweden and makes it clear that the Netherlands had a higher GDP per capita already before 1650 and the English GDP per capita overtook that for Italy after 1700.[8]

Before proceeding, it is also important to consider that in 1629–1630 most of Northern Italy suffered from a severe plague causing the population to decrease and real wages to increase for a period that might affect some of the first observations in our dataset which start in 1650. We nevertheless initially concentrate on the years from 1650 (when the demographic data starts) until 1799. The latter date is arguably arbitrarily chosen. However, we are interested in Malthusian mechanisms, and according to the UGT literature, we should not include changes associated with industrialization, as only the preindustrialized period should, in theory, be Malthusian. According

[5] The robustness checks are available on request. We also considered using GDP data as a robustness check. However, these estimates (Malanima 2011) are based on real wages and thus would not be an independent check.

[6] The data presented by Malanima does not include these other regions because of the shorter period covered.

[7] The unification in 1861 is also a first reason for why we do not use the entire sample of wages available.

[8] However, Malanima (2013) argues that the Italian GDP was overtaken by the English only after the second half of the eighteenth century. In Fig. 1 we use data from Maddison for all four countries because it makes it easier to compare them, even though other measures are available.

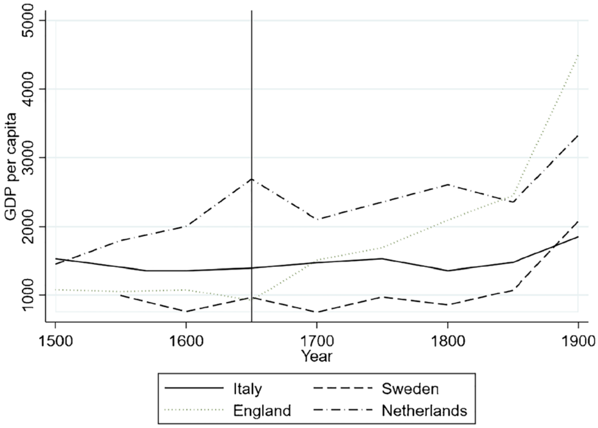

Fig. 1 GDP per capita for Italy, England, Sweden and the Netherlands in 1990 international GK$. Sources: Bolt and van Zanden (2014). The vertical line indicates when our dataset for the analysis starts

to Malanima (2011), a period of modern growth in Italy has its early start in the 1820s, and we should thus stop our analysis before then.

Furthermore, there are additional reasons for stopping our analysis in 1799 since the nineteenth century led to important changes. As mentioned above, Italy was unified in 1861. Moreover, the first signs of a demographic transition can be traced to the 1870s. Most important here, however, is that Napoleon invaded Italy in 1796 and the Napoleonic wars only ended in 1815. During the Napoleonic occupation, apart from being at war, Northern Italy underwent many reforms affecting the entire region. Given that the first decade of the 1800s, right before the beginning of modern growth, was affected by war and reform, it seems wise to exclude this period from the analysis. We thus decide to use a period spanning from 1650 to 1799 in our main analysis. To support our choice of end date, we have performed a Wald test for structural breaks for each of the four variables and for the known break date, 1799, and find that this cannot be rejected as a break date for any of the variables. However, as a robustness check, we extend the sample to 1881 later in the analysis in a recursive regression study, with the effect that some of the results become less significant.[9]

Figure 2 illustrates our data in both levels and differences for the period 1650–1799. The first point to notice is that real wages display a negative trend over time, which distinguishes Northern Italy from other regions where the same approach has been used, i.e., England, Scandinavia, and France. The trend becomes even clearer when using a longer time series of real wages.[10] Malanima (2003, 2006) explains this, in part, by stagnant nominal wages combined with increases in the price index caused by bad weather. A concern with using the real wage rate is that it does not consider that, when the wage rate falls, workers will increase the hours worked, or women and children will join the working force, to compensate for the decrease and keep income at the same

[9] We find in fact that the real wages appear more stationary for this sample. More details and the full results are available on request.

[10] Malanima's complete series starts in 1290.

level.[11] However, real GDP estimates which, since they are on an annual basis, are insensitive to the number of days worked, still exhibit a negative trend, although less pronounced than for the real wage rate.

Furthermore, both marriage rates and birth rates also seem to decrease over time, while the death rate oscillates around some stable value for the entire period represented. Finally, it can be noticed from the graphs that lw, cbr, and cmr all seem non-stationary, while their first differences appear much more stationary. cdr, on the other hand, appears more stationary in levels.

Since we will be looking for cointegrating relationships between the variables, the order of integration is important for the suitability of our chosen econometric framework even though using another econometric approach could also result in spurious regression results in case the included variables are of different orders of integration. The order of integration can be determined in two ways: (1) using a univariate approach such as ADF or KPSS tests and (2) using a system-based approach, i.e., testing the rank. Table 1 shows the univariate Augmented Dickey-Fuller and the Kwiatkowski, Phillips, Schmidt, and Shin test statistics both with and without a trend, for all four variables using three, four, and five lags.

From Table 1, it is clear that the ADF test is quite sensitive to the number of lags included, showing evidence for a unit root only for the crude birth rate and weakly for wages, when using our preferred model with three lags.[12] When including five lags, the crude marriage rate also shows non-stationarity while the crude death rate remains stationary. Turning to the KPSS test for stationarity, the variables seem less stationary, given that already with three lags, there is strong evidence that only the crude death rate is stationary. We thus believe that univariate tests show some evidence in favor of using the cointegration approach. However, even though cdr might indeed be I(0), we can anyway proceed with the cointegration analysis, but with the expectation that we do not find cointegrating relations including cdr—since it is already stationary, it would effectively "cointegrate" with itself (the same result found with English data by Møller and Sharp 2014).

Regarding stationarity of our variables, it should also be noted that one of the first steps in the cointegrating approach is to determine the rank of the system.[13] The determination of the rank is, as already mentioned, a system-based approach to testing non-stationarity in the variables where finding reduced rank is evidence that the variables are non-stationary. Furthermore, it is possible to find stationarity using univariate econometric methods, but still find non-stationarity when using the system-based approach (Johansen 1996). We follow Møller and Sharp (2014) in believing that the latter method is more natural to use, given the nature of interdependency in our variables according to the Malthusian model. Therefore, we only use the univariate ADF and KPSS tests as a first indication of the non-stationary nature of our variables, while our final decision to use the cointegrated approach, is based on the trace test which clearly shows reduced rank. In the

[11] According to Malanima (2006), there was indeed an increase in the working hours in Northern Italy along with a rise in non-labor incomes.

[12] The number of lags used in our model will be discussed in more detail in Section 5.2, where it is found that three lags are needed to avoid issues with autocorrelation in the stationary VAR.

[13] We will discuss this more in detail in later sections.

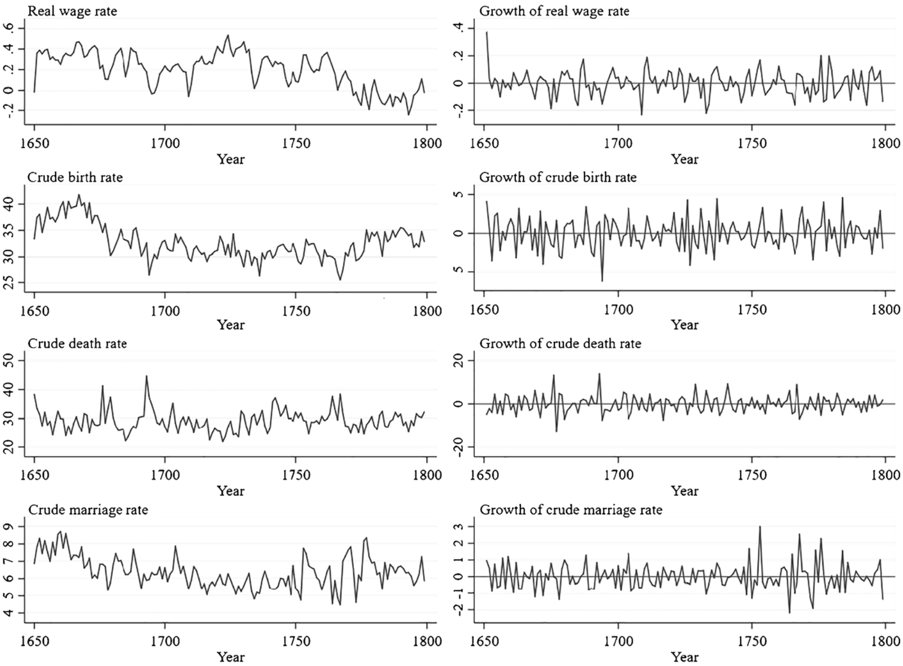

Fig. 2 Real wages and vital rates in levels and differences (1650–1799). Sources: The time series for real wages has been collected and estimated by Paolo Malanima and the vital rates all come from Galloway (1994)

remainder of our analysis, we follow the standard procedure (as described by Juselius 2006) and begin with the least restrictive model, a stationary VAR model.

5 Analysis

5.1 The econometric framework

Møller and Sharp (2014) explain how the Malthusian model presented in Section 3 can be formalized as a cointegrated VAR model in the four known variables, $\{w_t, b_t, d_t, m_t\}$. Thus, all the estimations are general VAR(k)s in Error Correction Mechanism form:

$$\Delta x_t = \Pi x_{t-1} + \Gamma_1 \Delta x_{t-1} + \ldots + \Gamma_{k-1} \Delta x_{t-(k-1)} + \phi D_t + \varepsilon_t \quad (8)$$

where $x_t = (w_t, b_t, d_t, m_t)'$ and D_t is a $d \times 1$ vector of dummies that initially will be left empty. In Eq. 8, we are only interested in the matrix Π, which contains the parameters of interest, i.e., the preventive check, the positive check, and the birth relation. Π can be found by solving for the four observable rates in Eqs. 1–7, with respect to their first differences: Δw_t, Δb_t, Δd_t, and Δm_t. Π is a 4×4 matrix with the determinant:

Table 1 ADF and KPSS test statistics

Variable	Trend	Subsample (1650–1799)		Full sample (1650–1881)	
		ADF	KPSS	ADF	KPSS
		5 lags			
lnw	No	−1.597***	1.31***	−2.495***	2.250***
lnw	Yes	−2.563	0.256***	−3.426**	0.190**
cbr	No	−2.032***	1.02***	−1.918***	1.030***
cbr	Yes	−1.750***	0.434***	−2.301***	0.621***
cdr	No	−4.377	0.070	−4.868	0.389***
cdr	Yes	−4.394	0.065	−5.076	0.057
cmr	No	−2.606*	0.846***	−2.259***	1.490***
cmr	Yes	−2.543***	0.436***	−2.953***	0.586***
		4 lags			
lnw	No	−1.982***	1.510***	−2.768**	2.600***
lnw	Yes	−3.060***	0.286***	−3.845*	0.211**
cbr	No	−2.073***	1.200***	−2.202***	1.220***
cbr	Yes	−2.046***	0.503***	−2.479***	0.728***
cdr	No	−4.537	0.074	−5.077	0.420***
cdr	Yes	−4.595	0.069	−5.303	0.093
cmr	No	−3.344*	0.945***	−3.086*	1.700***
cmr	Yes	−3.427*	0.480***	−3.799*	0.659***
		3 lags			
lnw	No	−2.538***	1.810***	−3.157*	3.080***
lnw	Yes	−3.734*	0.329***	−4.470	0.239***
cbr	No	−2.212***	1.460***	−2.468***	1.480***
cbr	Yes	−2.286***	0.605***	−2.711***	0.886***
cdr	No	−4.228	0.082	−5.274	0.389***
cdr	Yes	−4.242	0.076	−5.455	0.102
cmr	No	−3.972	1.080***	−3.830	2.00***
cmr	Yes	−4.218	0.537***	−4.503	0.758***
No. of observations		144		232	

The table shows the test statistics from the ADF test for unit root and the KPSS test statistics for stationarity. For the ADF test, the null hypothesis is the presence of a unit root while, for the KPSS, the null hypothesis is that the variable is trend/level stationary. Thus, the level of significance (and the stars) has a different interpretation, depending of the performed test. For the ADF: * $|z| < crit_{10}$; ** $|z| < crit_5$; *** $|z| < crit_1$. For the KPSS: * $|z| > crit_{10}$; ** $|z| > crit_5$; *** $|z| > crit_1$

$$\det(\Pi) = c_1(a_1 + a_3) \tag{9}$$

If $\det(\Pi) = 0$ then x_t is non-stationary and Π has reduced rank, $r < 4$. This can be parametrized as a non-linear testable restriction:

$$\Pi = \alpha\beta' \tag{10}$$

where α and β are $4 \times r$ matrices with $r < 4$. Finding reduced rank is a clear contradiction of the Malthusian model and indicates that the observable variables interact in a non-stationary VAR, motivating the cointegration approach applied here. As can be seen from Eq. 9, the proposed framework suggests two explanations for the presence of reduced rank:

$$a_1 + a_3 = 0$$

$$c_0 = 0$$

The first case, $a_1 + a_3 = 0$, implies that the sum of the positive and the preventive check is negligible, resulting in almost no effect from the real wage to population growth. This can be tested empirically by imposing the following restrictions on α and β':

$$\begin{aligned} \alpha &= \begin{pmatrix} 0 & 0 & -c_1 \\ 0 & 1 & e_1 \\ -f & -1 & a_3c_1 + 1 \\ -1 & 0 & -a_5c_1 \end{pmatrix} \\ \beta' &= \begin{pmatrix} -a_5 & 0 & 0 & 1 \\ 0 & 1 & 0 & -f \\ 0 & 1 & -1 & 0 \end{pmatrix} \end{aligned} \tag{11}$$

\eqno\tflt="P7B6C"(11)

The second explanation, $c_1 = 0$, which can be related to the post-Malthusian hypothesis, is that real wages do not decline when the population increases, and thus there are no diminishing returns to labor, or expressed in another way, wages are weakly exogenous. In equation form the restrictions are:

$$\begin{aligned} \alpha &= \begin{pmatrix} 0 & 0 & 0 \\ e_1f & -(1-e_1) & -e_1 \\ 0 & 0 & -1 \\ -1 & 0 & 0 \end{pmatrix} \\ \beta' &= \begin{pmatrix} -a_5 & 0 & 0 & 1 \\ 0 & 1 & 0 & f \\ a_3 & 0 & 1 & 0 \end{pmatrix} \end{aligned} \tag{11}$$

The fact that all three parameters in the first row of α are zero, shows that wages become weakly exogenous when $c_1 = 0$ is imposed.

In both cases, the β is identified (see Møller and Sharp 2014). In Section 5.3, the hypotheses will be tested on the northern Italian data by imposing the two presented restrictions in an empirically applicable version.[14]

5.2 Preliminary analysis

To have a well-specified model, there are several things to consider before estimating the final CVAR.[15] Following Møller and Sharp (2014), we start by estimating an unrestricted VAR.

The analysis is dependent on the correct choice of the lag length, to avoid issues regarding autocorrelation. In a pre-estimation test, we find that including three lags is most appropriate.[16] In contrast to the two lags often found sufficient for analyzing macroeconomic data (see the discussion in Juselius 2006), it seems that demographic data requires an extra lag, since three lags were also found necessary when modeling the English data by Møller and Sharp (2014) and also for Italy by Fernihough (2013).

An analysis of the residuals reveals, as expected, no problems with autocorrelation in the unrestricted VAR model. However, the assumption that the residuals are normally distributed is convincingly rejected. Univariate analyses of the variables reveal that non-normality is mainly due to the non-normality of lw and cdr. For the former, this is caused primarily by one large negative residual (− 3.52) in the year 1709. This is probably due to the outcome of the War of the Spanish Succession, when Northern Italy came under the Austrian crown. Non-normality of cdr is primarily the result of two larger positive residuals (2.90) in 1676 and (4.28) in 1693.[17] The former is attributable to famine while the latter is attributable to an outbreak of smallpox. All three events can be considered as exogenous shocks and thus we model them using dummies of the form (…0001000…). That the Spanish war and the epidemic of smallpox are exogenous shocks is clear. We argue that in this specific case, famine can also be considered to be an exogenous shock, because it was caused by bad weather conditions, having a huge one-time impact on harvests and thus increasing mortality. Including these dummies considerably improves the model specification. Nevertheless, problems with non-normality and autoregressive conditional heteroskedasticity have been proved to be less severe for the cointegration analysis than problems with autocorrelation (Juselius 2006, Rahbek et al., 2002), the latter of which is not an issue when using three lags.

When including dummies in the analysis, it is important to decide whether to include them unrestricted or restricted in the cointegration model. A distinction can be made between innovational outliers (IO) which are due to extraordinary exogenous shocks such as warfare and epidemics and additive outliers (AO) which are due to measurement errors. The former should enter the model unrestricted while the latter should

[14] In the empirical analysis, we employ a slightly different model that allows for more flexible dynamics of adjustment, but with the same long-run properties and interpretation as the model presented in this section. For a complete discussion on the empirically applicable model, we refer to Møller and Sharp (2014).

[15] The regression analysis has been performed in PcGive, OxMetrics 4.02 and STATA 16.1.

[16] The results from the pre-estimation analysis are available on request.

[17] Usually, according to Hendry and Juselius (2001), an outlier is defined by a standardized residual exceeding 3.3. However, the inclusion of a dummy controlling for 1676 improves the specification considerably and we thus choose to include it even though the residual is less than 3.3.

enter restricted in the cointegrating equations. As all three identified outliers have been caused by well-documented episodes of exogenous shocks, we choose to include them as unrestricted in the analysis.[18]

Finally, before testing the two restrictions in Eqs. 11 and 12, we test the rank of the long-run restriction, Π, i.e., the number of possible cointegrating relations. In the specification including the three dummy variables, $D1676$, $D1693$, and $D1709$, the test clearly suggests the rank to be $r = 3$. This indicates that the rates are persistent and thus not consistent with the Malthusian model described in Section 3. As a robustness check of the non-stationarity, i.e., the rank, we proceed with a forward recursive analysis of the trace test using a fixed start point in 1650. This exercise is done both with and without the dummy variables included, to determine how they influence the choice. By estimating recursively, it is possible to determine whether the rank changes over time, and to assess when the non-stationarity is empirically relevant.

Figure 3, panel a shows the trace statistics from the forward recursively estimated trace test of $H(3)$ against $H(4)$, i.e., the hypothesis that $r \leq 3$ against $r \leq 4$: when the trace test is statistically significant, it is evidence against $H(4)$. From Fig. 3, panel a, it appears clearly that $r \leq 3$ for all recursions both with and without dummies included, given the trace statistics are well below the 5%critical value. To assess whether it is reasonable that $r = 3$ and not less, we perform the same exercise for the trace test of $H(2)$ against $H(3)$, see Fig. 3, panel b. Since the trace statistics in this case are much closer to the 5% critical value, especially for the later parts of the sample, we are confident that $r = 3$.[19]

From Fig. 3, it is also evident that the trace test is influenced by the inclusion of dummies, but not to a large extent, since the graphs are very similar. Finally, it might be noticed that the non-stationarity is empirically relevant for the entire period, especially for our chosen sample, 1650–1799. It is possible to notice how the trace statistics start increasing steadily around 1799, which gives another reason to stop our analysis in 1799.[20] Backward recursive estimates of the trace test again show how using the entire sample results in more stationarity, and the results are available on request.

Given that we find evidence for $r = 3$, we proceed by testing the two proposed restrictions in (13) and (14).

5.3 Cointegration analysis

The results from testing the restriction in Eq. 11 can be seen in Table 2, while the results of the post-Malthusian hypothesis, Eq. 12, are found in Table 3 (p values in parentheses). In the final specifications, the trend has been restricted to zero when its coefficient was not significantly different from zero, while the dummies enter unrestricted in all specifications.

[18] Including the dummies restricted in the analysis does not change the results much. The rank determined by the trace test is the same as in the unrestricted case, and the parameters of the cointegrating matrices are almost identical.

[19] This is most true for the model including the dummy variables. Apart from the trace test, we also used the information criteria and the maximum eigenvalue statistic for the determination of the rank, and they all support this finding.

[20] The choice of our end point has been discussed more in detail in Sec. 4.

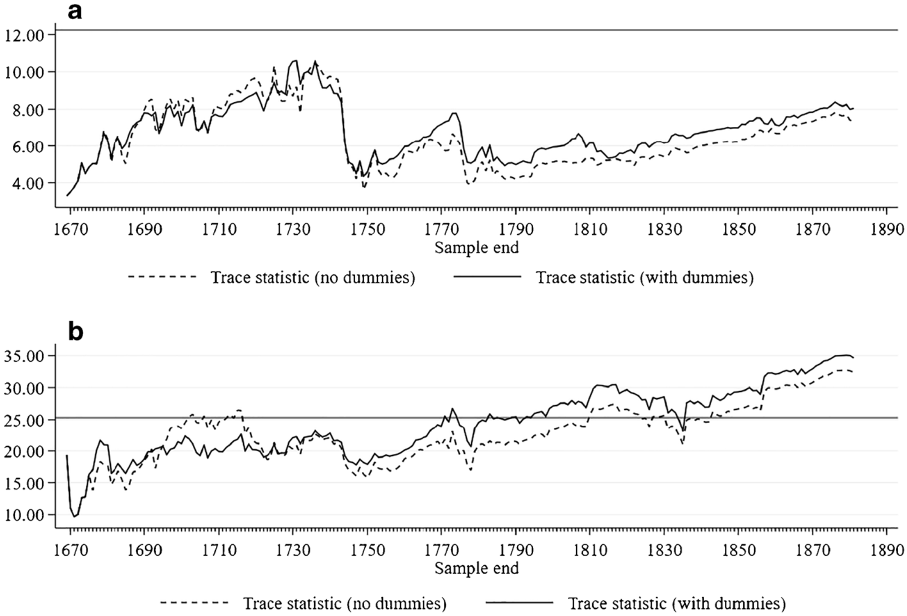

Fig. 3 Recursively calculated trace test. Panel **a** presents the forward recursively computed trace statistics for the trace test $\boldsymbol{H}(\mathbf{3})$ against $\boldsymbol{H}(\mathbf{4})$**,** and panel **b** presents the trace statistics for $\boldsymbol{H}(\mathbf{2})$ against $\boldsymbol{H}(\mathbf{3})$. The dashed lines represent the model without dummies included, while the solid lines represent the model with dummies. The horizontal lines show the **5**%critical values. The sample start-point is fixed in 1650 while the end-point changes

Table 2 CVAR regression results for the specification considering homeostasis, $a_3 + a_3 = 0$, for the sample 1650–1799

α				β'					
					w_t	b_t	d_t	m_t	Trend
Δw_t	0.000	0.000	−0.001 (0.365)	β_1'	1.441 (0.067)	0.000	0.000	1.000	0.001 (0.003)
Δb_t	0.296 (0.174)	−0.204 (0.001)	−0.040 (0.184)	β_2'	0.000	1.000	0.000	−2.534 (0.000)	0.000
Δd_t	1.567 (0.000)	0.423 (0.001)	−0.350 (0.000)	β_3'	0.000	1.000	−1.000	0.000	0.000
Δm_t	−0.349 (0.000)	0.000	−0.012 (0.349)						
Number of obs.				147					
LR test of identifying restrictions $chi^2(5)$				24.88 (0.000)					

The brackets contain the p values. β_1' represents the preventive check relation (a_5), β_2' shows the birth relation, and β_3' represents the assumption $a_1 + a_3 = 0$. The α matrix contains the adjustment parameters, i.e., the speed of adjustment when the model is out of equilibrium

Table 3 CVAR regression results for the specification considering the post-Malthusian hypothesis, $c_1 = 0$, for the sample 1650–1799

α				β'					
					w_t	b_t	d_t	m_t	Trend
Δw_t	0.000	0.000	0.000	β_1'	2.558 (0.022)	0.000	0.000	1.000	0.011 (0.012)
Δb_t	0.000	−0.258 (0.000)	−0.076 (0.068)	β_2'	0.000	1.000	0.000	−4.083 (0.000)	0.000
Δd_t	0.000	0.000	−0.540 (0.000)	β_3'	2.499 (0.293)	0.000	1.000	0.000	0.000
Δm_t	−0.342 (0.000)	0.000	0.000						
Number of obs.				147					
LR test of identifying restrictions $chi^2(5)$				28.97 (0.001)					

The brackets contain the p values. β_1' represents the preventive check relation (a_5), β_2' shows the birth relation, and β_3' represents the positive check relation (a_3). The α matrix contains the adjustment parameters, i.e., the speed of adjustment when the model is out of equilibrium

In Table 2, we have replaced the positive check with the assumption of homeostasis (i.e., that in equilibrium $a_1 + a_3 = 0$). The first cointegrating relationship, β_1', represents the preventive check; the second, β_2', represents the birth relation; and the third, β_3', represents the assumption of homeostasis, $a_1 + a_3 = 0$. Even though the parameters in the cointegrating vector (preventive check and birth relation) and most of the adjustment parameters are significantly different from zero, the restriction cannot be accepted at any conventional level given a p value of 0.000.

In Table 3, we test the post-Malthusian hypothesis, i.e., $c_1 = 0$, where weak exogeneity is imposed on wages. Both checks and the birth relation are present. The weak exogeneity on wages comes from the first row in the adjustment matrix, $\alpha_{1,\ i}$, where all coefficients are restricted to zero. This means that wages do not adjust after a shock in one of the other variables. The cointegrating relations are the same as before apart from the third, β_3', which has been substituted with the positive check relation. Again, the restriction cannot be accepted given a very small p value of 0.001. The parameters of the preventive check and the birth relation are both significantly different from zero, whereas the positive check is not (this was to be expected as the death rate appeared to be I(0)). All parameters in the adjustment matrix have the expected sign and are significant.

From the above regression results, it can be concluded that none of the presented theoretical explanations of the reduced rank can be accepted, indicating that the Italian data exhibit dynamics not included in the Malthusian model from Section 3, including the restrictions compatible with a post-Malthusian regime. Extending the analysis to include the complete data set (1650–1881) does not change this conclusion. An inspection of Tables 2 and 3 also reveals another interesting aspect. In both, the parameter on the marriage rate (a_5) does not have the expected sign. At first glance, this seems to indicate that marriages are influenced negatively by real wages, i.e., that higher wage rates lead to fewer marriages and consequently to fewer births, which seems highly contradictory to both what we might expect from the period under consideration and the theory presented. As a robustness check, and considering this surprising result in the perspective of UGT, we also conducted the analysis without marriages as in Klemp and Møller (2016). However, the sign on the birth rate coefficient is negative and significantly different from zero, again indicating a negative effect of wages on births. Our main results are thus consistent with the simpler version but a little puzzling from a theoretical standpoint. We will return to this issue in Section 6 where we discuss some of the possible reasons, which can apply both to the model with and without marriages.

To gain a greater understanding of why neither of the restrictions are accepted, we proceed by relaxing the restrictions on the adjustment parameters. In the first case ($a_1 + a_3 = 0$), the restriction is still rejected while in the second case, ($c_1 = 0$), we find a specification that we cannot reject based on the high p value obtained. We find that relaxing the restrictions on $\alpha_{1,i}$, can be accepted and, as can be seen in Table 4, two of the three adjustment parameters are significantly different from zero (adjustment parameters of wages in the preventive and positive check relations). This indicates that these were the reason for rejection of the results in Table 3. Furthermore, the preventive check and the birth relation parameters are still significant with the same sign, while the positive check is insignificant.

The conclusion that two parameters in the first row of the adjustment matrix necessarily must be different from zero indicates clearly that wages are not weakly exogenous in the system, pointing towards an economy which is more Malthusian than post-Malthusian. The restrictions cannot be rejected based on the high p value of 0.507.

Table 4 CVAR regression results for the alternative specification without weakly exogenous wages for the period 1650–1799

α				β'					
					w_t	b_t	d_t	m_t	Trend
Δw_t	−0.045 (0.000)	−0.004 (0.206)	−0.006 (0.014)	β_1'	5.244 (0.000)	0.000	0.000	1.000	0.021 (0.000)
Δb_t	0.000	−0.250 (0.000)	−0.068 (0.101)	β_2'	0.000	1.000	0.000	−4.664 (0.000)	0.000
Δd_t	0.000	0.000	−0.543 (0.000)	β_3'	2.600 (0.268)	0.000	1.000	0.000	0.000
Δm_t	−0.282 (0.000)	0.000	0.000						
Number of obs.				147					
LR test of identifying restrictions $chi^2(5)$				6.284 (0.507)					

The brackets contain the p values. β_1' represents the preventive check relation (a_5), β_2' shows the birth relation, and β_3' represents the assumption $a_1 + a_3 = 0$. The α matrix contains the adjustment parameters, i.e., the speed of adjustment when the model is out of equilibrium. This table differs from Table 3, in that the first row of adjustment parameters, (Δw_t), are no longer restricted to zero

In Table 5 it is possible to read directly the estimates of the preventive check, the positive check, and the birth relation results obtained from Tables 2, 3, and 4. Here, it becomes clear how the sign of the preventive check remains negative in all specifications and that the positive check is never significantly different from zero.

As mentioned in Section 4, we also conducted the analysis using two different measures of real wages to investigate whether there are some important differences between rural and urban areas, as they in periods exhibit markedly different movements. However, both show similar results and the sign on the wage rate in the marriage equation is always the same. Our findings are also insensitive to using the inverse of wheat prices, indicating that the results presented in Tables 2, 3, and 4 are robust to the measure of living standards used.

5.4 Recursive estimates

As a final step in the empirical analysis, we present the results of a forward-recursive regression analysis to show how the results from the previous section change over time and when including the complete series available. In the forward-recursive analysis, one more observation is added in each recursion and this allows us to investigate changes in the parameters of interest and the test statistic of rejection. However, the recursive estimation keeps all the observations from the earlier years and thus tends to underestimate potential changes later in the sample. We have therefore also run a rolling windows analysis based on 70-year rolling subsamples to see whether there are relevant changes at the end of the sample. The analysis has been performed for all three specifications from Section 5.3, and the forward recursive graphs can be seen in Figs. 4, 5, and 6. The first panels in each figure show the point estimates of the preventive check, ($-a_5$), the birth relation and the positive check, ($-a_3$), while the last panel shows the corresponding p value of the test statistic. Whenever the p value is below the significance level (5% in the figures), the estimated hypothesis is rejected. For all three figures, the estimated coefficients converge to a stable value and the preventive check is always with the unexpected sign, indicating that this result is robust to the choice of any

Table 5 Summary table of estimation results

	Homeostasis hypothesis ($a_1 + a_3 = 0$)	Post-Malthusian hypothesis ($c_1 = 0$)	Chiarini's hypothesis
Preventive check (a_5)	−1.441 (0.067)	−2.558 (0.022)	−5.244 (0.000)
Positive check ($-a_3$)		−2.499 (0.293)	−2.600 (0.268)
Birth relation	2.534 (0.000)	4.083 (0.000)	4.664 (0.000)
Wages exogenous	No	Yes	No
Number of obs.	147	147	147
p value of overidentifying restrictions	0.000	0.001	0.507

Summary of the results in Tables 2, 3, and 4. The first column refers to Table 2, the second column refers to Table 3, and the third column refers to Table 4. The brackets contain the p values subsample. In Fig. 5, the preventive check oscillates more at the beginning, when including only the first years, but when more observations are included, the parameter again converges and stays positive. The parameter of the birth relation always has the same sign and oscillates only a little, while the positive check parameter oscillates more exhibiting a negative value at one point but converging as the sample size is increased. By looking at the last panel in Figs. 4 and 5, the restrictions can almost always be rejected indicating again that the results from Section 5.3 are robust to the choice of the observations included. In Fig. 6, which represents the alternative specification from Table 4, the p value oscillates more but is often higher than 5% and, especially at the beginning of the sample, we obtain very high values. When including more observations from the end of the sample (starting from around 1815), the p value converges to a low value and the specification is always rejected.

When using rolling windows of 70-year subsamples, the conclusions are much the same (the results are available on request). In all three cases, most of the subsamples can reject all three specifications apart from a few starting from 1750 which can accept the homeostasis hypothesis and some subsamples accepting the final specification from Table 4.

From the above analysis, it can be concluded that there are no clear cut-offs where the dynamics change for any of the three specifications apart from the end of the sample when the restrictions can never be accepted.

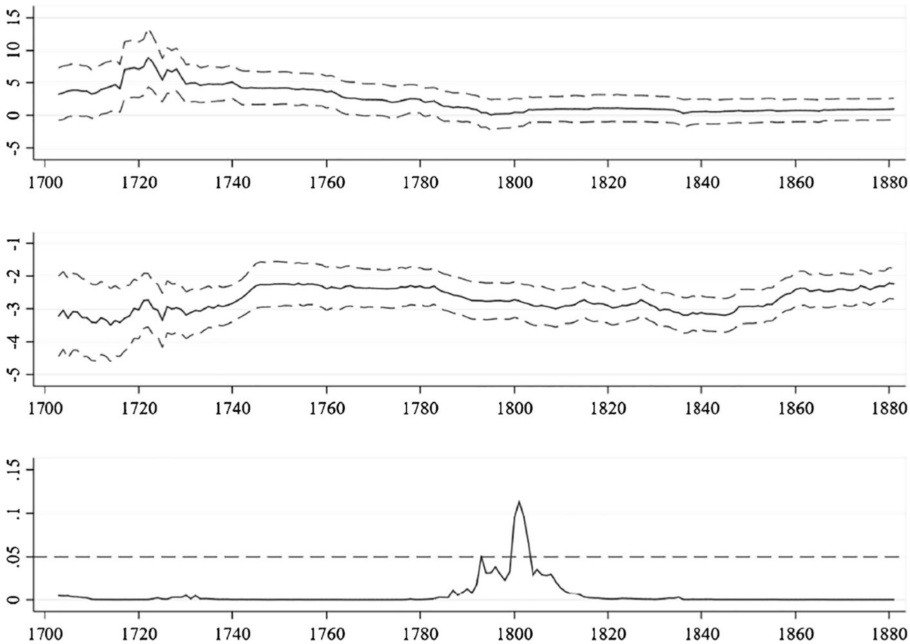

Fig. 4 Recursive estimates for the specification considering homeostasis, $a_1 + a_3 = 0$, for the sample 1650–1881. (top panel) The point estimate of the preventive check coefficient, stated as $\boldsymbol{a_5}$, together with the 2× standard error limits; (middle panel) point estimate of the birth relation coefficient together with the 2× standard error limits; (bottom panel) the p values of the test statistic corresponding to the homeostasis hypothesis, where values below the dashed line indicate a rejection of the hypothesis at the 5% significance level. Sample start is fixed at 1650

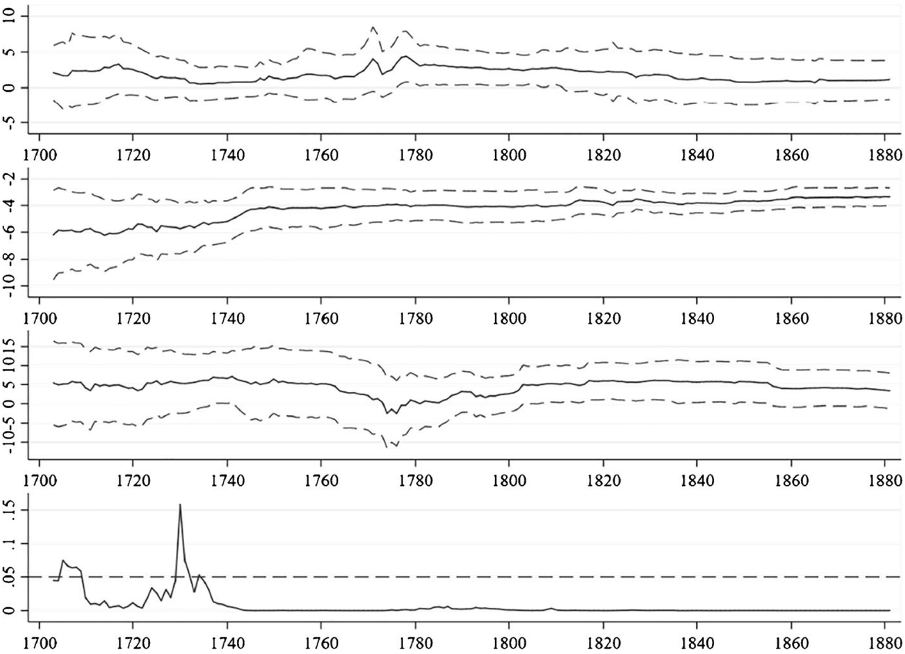

Fig. 5 Recursive estimates for the specification considering the post-Malthusian hypothesis, $c_1 = 0$, for the sample 1650–1881. (top panel) The point estimate of the preventive check coefficient, stated as $\boldsymbol{a}_5$, together with the 2× standard error limits; (top middle panel) the point estimate of the birth relation coefficient together with the 2× standard error limits; (middle bottom panel) the point estimate of the positive check coefficient, stated as $\boldsymbol{a}_1$, together with the 2× standard error limits; (bottom panel) the p values of the test statistic corresponding to the homeostasis hypothesis, where values below the dashed line indicate a rejection of the hypothesis at the 5% significance level. Sample start is fixed at 1650

6 Discussion and the preventive check

In all three specifications, the sign of the preventive check is found to indicate that increases in the real wage caused a decrease in the marriage rate and consequently a decrease in the number of births. This result is in contradiction with the Malthusian preventive check and might be interpreted as evidence in favor of the quantity-quality trade-off emerging during the process of industrialization. However, the sign is the same for almost all subsamples in both the recursive and rolling windows analysis, indicating that the negative relationship starts much earlier than the process of industrialization. It thus seems implausible to claim the existence of a quantity-quality trade-off based on the present analysis. It is also contradictory to the results found by Fernihough (2013), who finds evidence supporting the preventive check with the expected sign but using a different approach. Furthermore, other studies following the cointegration approach find evidence for a preventive check with the expected sign (Møller and Sharp 2014 and Klemp and Møller 2016). On the other hand, as mentioned above, like us Chiarini (2007, 2010) finds evidence of a negative feedback from wages to population, and we thus find evidence in favor of his suggestion of an old age security motive for this relationship. There is thus some evidence that Italian wage-population dynamics are different from other European experiences.

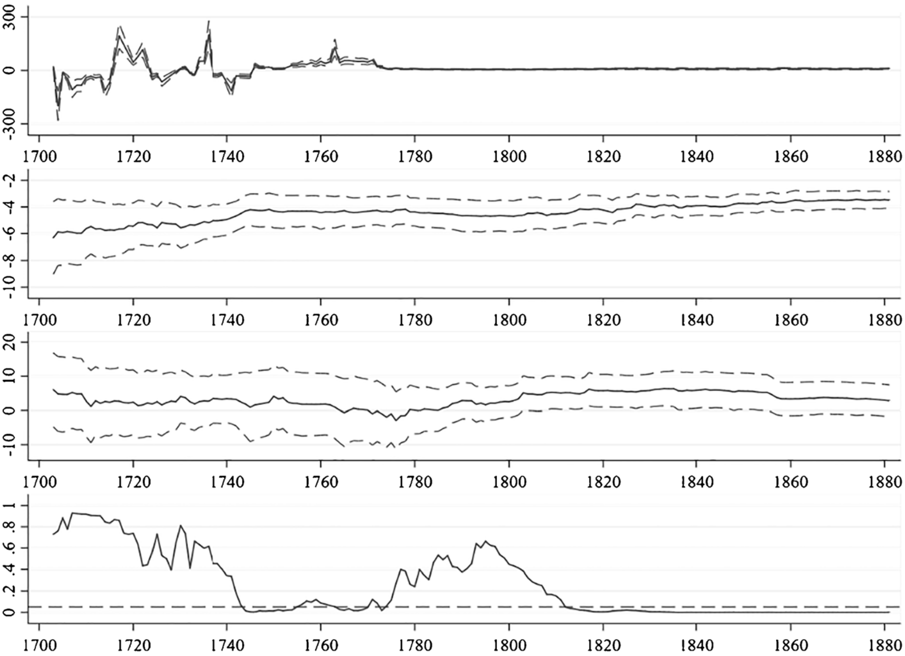

Fig. 6 Recursive estimates for the alternative specification without weakly exogenous wages for the period 1650–1881. (top panel) The point estimate of the preventive check coefficient, stated as $\boldsymbol{a_5}$, together with the 2× standard error limits; (top middle panel) the point estimate of the birth relation coefficient together with the 2× standard error limits; (middle bottom panel) the point estimate of the positive check coefficient, stated as $\boldsymbol{a_1}$, together with the 2× standard error limits; (bottom panel) the $\boldsymbol{p}$ values of the test statistic corresponding to the homeostasis hypothesis, where values below the dashed line indicate a rejection of the hypothesis at the 5% significance level. Sample start is fixed at 1650

It should also be mentioned that this is also consistent with the work of Chiarini and Marzano (2018) who study the relationship between agricultural productivity, population, and urbanization.[21] In the period we are covering, Italian urbanization was very different from many other countries. This might be part of the explanation for the different dynamics, considering the important role of urbanization in a transition towards sustained growth. Italy experienced an early wave of urbanization already from the fifteenth century. By the time other countries began to urbanize, Italy experienced a decline in its urban population growth because of the coexistence of a decline in agricultural productivity. Thus, by the late seventeenth century, when our analysis begins, Italy was among the least urbanized countries, suggesting that Italy had a different transition period to sustained growth. Chiarini and Marzano (2018) find evidence for a primitive mechanism of human capital accumulation caused by the early urbanization attracting the young and more qualified to the cities. This finding is consistent with the negative effect of wages on births we find. On the other hand, they find that increases in urbanization led to an increase in population. This might seem to contrast with our results, since we study a period when urbanization was increasing again. However, they find that this effect is not long lasting and would therefore not be visible in our analysis of long-run relationships.

[21] See also Gollin et al. (2007).

Our finding that diminishing returns are driven by changes in fertility rather than mortality, is the natural conclusion to be drawn from Galloway (1994), who noted that changes in the population growth rate were dominated by fluctuations in fertility. Most significantly, our finding of declining income due to diminishing returns supports the claims of several scholars. Malanima (2003, 2006) suggests that the decline in real wages was partly due to diminishing returns—after all, population doubled between 1700 and 1861—but he also gives other reasons, most significantly a fall in temperatures in the second half of the eighteenth and the first two decades of the nineteenth century. Since more than 40% of Italy's surface is hilly, Italian agriculture was hit particularly hard by the temperature drop, which made it more difficult to grow crops on high land. Other innovations might have offset this, such as the spread of maize, mulberry plantations and the impact of work intensification as people began to work more hours a day both to increase the per hectare product and to exploit new possibilities of income such as protoindustrial activities (especially in silk manufacture). However, these did not offset the negative effects of the population increase until the 1820s, and even then, from 1835 bad harvests, silkworm and vineyard diseases caused agricultural production to drop again, and it was only in the second half of the nineteenth century that technological advance was proceeding rapidly enough to support increasing incomes.

Finally, the fact that we find the preventive check to be influenced negatively by wages indicates that nuptiality was also being determined by noneconomic factors, i.e., societal norms. This is likely in the light of our knowledge of Italian nuptiality patterns. The income restraint on marriage was not as strong as for example in England, where marriage involved the establishment of an entire new household. Malthus contrasted his ideal pattern of "individualistic marriage," which he linked to western prosperity, because it allowed for the operation of the preventive check, preventing population growth, encouraging savings, and keeping the price of labor high, with "collectivistic marriage,", prevalent in eastern countries. However, it has long been known that the mechanisms through which the economy regulated nuptiality (Hajnal 1965 and 1982) were much less important in Southern European countries (Viazzo 2003).

7 Conclusion

In contrast to England, preindustrial Northern Italy experienced a decline in real wages over the period considered here due to diminishing returns and a deterioration of the climate and agriculture. We find that in this particular setting, the preventive check did not have the expected sign while the positive check was only weak. The former is in contrast to some other studies but seems reasonable given the fact that Italians probably did not suffer the same income constraint on marriage as did western Europe. Instead, it was wages that were influenced by changes in population size.

This indicates, in contrast to England, Scandinavia and France, some evidence of diminishing returns to labor. This idea is supported by our analysis, when we specify an alternative hypothesis allowing for wages to be endogenous. Extending the sample to include observations until 1881 does not change our findings, and the recursive estimates of our alternative specification shows that around 1815, it becomes insignificant. Future work might try to better understand these results by extending the theoretical model of Møller and Sharp (2014) to include the additional dynamics present in Italy.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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